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A CLOUD ATLAS

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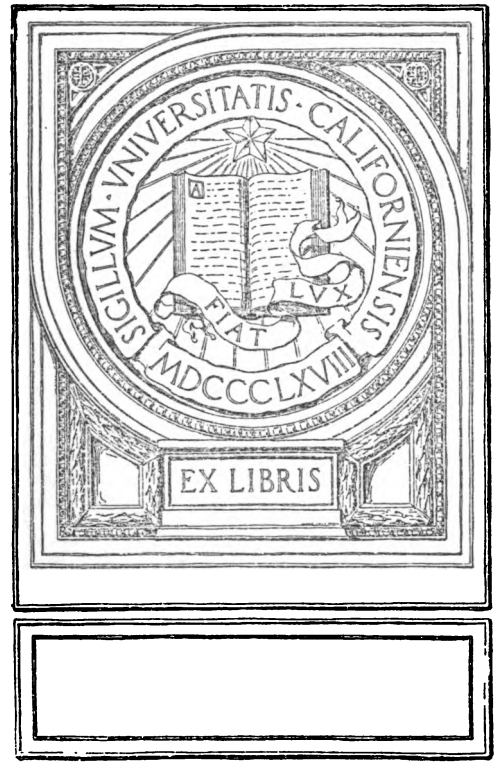

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A CLOUD ATLAS

By

ALEXANDER McADIE

Lawrence Rotch Professor of Meteorology, Harvard University, and Director of the Blue Hill Observatory. Formerly Professor of Meteorology, U. S. Weather Bureau, Lieutenant-Commander and Senior Aërographic Officer, U. S. N. R. F.

THE PASSING STORM

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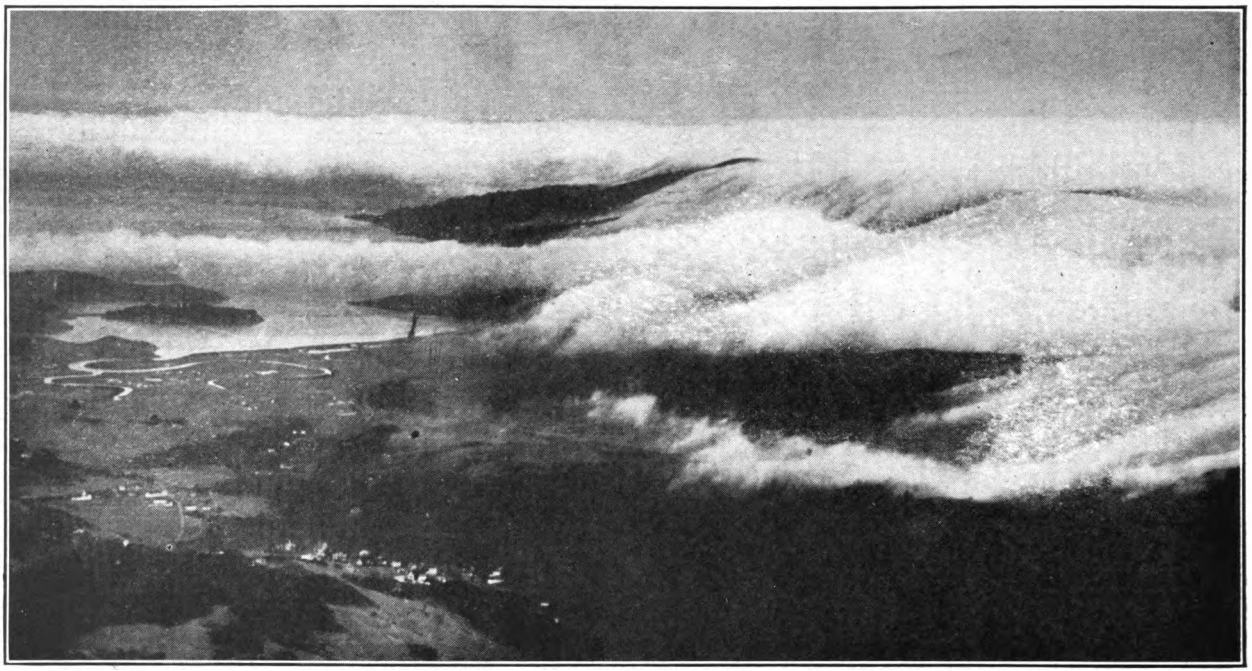

FIG. 1. NATURE'S THWARTED ATTEMPT AT RAIN MAKING
Summer fog streaming over the coast hills of California

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A CLOUD ATLAS

MAN'S ACHIEVEMENTS

1. Problems old and new. That stern and uncompromising prophet of Israel, Elijah the Tishbite, can be regarded as the first and incidentally a very successful rain maker. For he warned an evil king that no dew should form and not a drop of rain fall until certain reforms were made. At the end of three years of drought he had compassion on a suffering people and permitted rain to fall again. But there is discreet silence as to how it was done.

The first rain maker

This was quite different from the experience of poor old Job, when undergoing a rather stiff examination as to his ability to do things. He was asked if he could measure the bounds of the earth, bind the sweet influence of the Pleiades, or loose the bands of Orion.

Another question put to him was, "Canst thou send lightnings that they may go and say unto thee, Here we are?"

And, to complete his humiliation, there was a third "poser" to meet: "Canst thou lift up thy voice to the clouds that abundance of waters may cover thee? Who can number the clouds in wisdom, who can stay the bottles of Heaven?"

To all these questions Job had no answer. If, however, he could revisit the earth today, he would answer, "The bounds of the earth are fairly well known, and one axis of the globe is about twenty-five miles longer than the other. As for the bands of Orion, American astronomers have just taken the measure of that red-eyed star Betelgeux in the shoulder of the constellation Orion, finding it to be of the order two hundred forty million miles in diameter. They are now busy measuring other stars. As for sending lightning, well, hydroelectric power companies transmit the energy of mountain streams and waterfalls long distances; and this practically harnessed lightning says unto him who hath need, "Here we are; and at your service."

Modern progress

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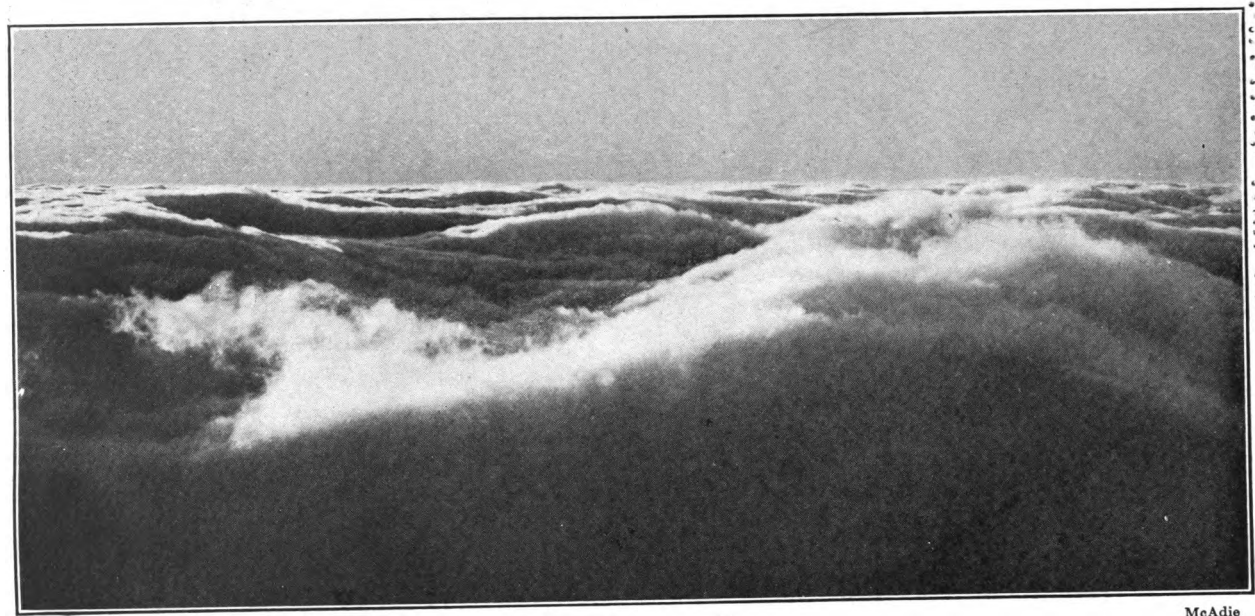

FIG. 2. ABOVE THE FOG

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Finally, and this is no less wonderful than the other achievements, the clouds are numbered and men are beginning to imitate the way of a bird in the air. They can indeed fly upside down, something which the birds cannot do; and they can fly far above the lower clouds, far above the habitat of birds; and a few of the most daring airmen have actually flown above the highest clouds; indeed beyond where clouds, even the thinnest and lightest, can be formed.

While man cannot yet call for rain and have "abundance of waters," nor yet bid the clouds depart and the rains cease — staying the bottles of Heaven, as the old phrase puts it — nevertheless, with his practical conquest of cloudland, and the ability to explore the region where the clouds form, he is on the verge of great advances in connection with all the processes of cloudy condensation in the free air. Increasing use of the air as a means of transportation will require and lead to a detailed knowledge of all the secrets of cloud building.

Classification of the clouds

In a way the clouds have been numbered ever since Luke Howard in 1802 proposed to divide them into the three great classes: stratus, or layer; cumulus, or heap; and cirrus, or feather; with modifications of these. The scheme was simple and answered very well for a number of years, but is now felt to be inadequate for the needs of airmen and aërographers.

Meteorologists of many countries gathered in international committees have greatly modified the original classification. The *International Cloud Atlas*, second edition issued in 1911, gives the new classification in detail. (See following section.)

But today a new order is coming, for we must now do more than merely *look* at a cloud. We must measure it, and interpret the cloud in terms of water content and temperature. Above all, we must know its direction and velocity, the duration and extent of air flow at that height, and what such conditions foretell as to coming weather.

We spoke above of the ability of man to go to the top of and even beyond cloudland. After long years of waiting it has come about that men are able to leave the earth, soar to the region of the highest clouds, and drop back to earth

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with the grace of a bird on the wing. It seems almost beyond belief that men can vault over the clouds. Within three years three American airmen have passed beyond the limits of cloudy condensation, far above the ice crystals of the cirrus clouds, those fine-spun filaments of the upper air. Rohlfs first at Mineola penetrated into the stratosphere, that is, the region next above cloudland. He reached a height of 9646 meters. Mt. Everest is only 8839 meters. Rohlfs was followed by Schroeder at McCook Field and the record raised to 9915 meters; and this in turn was broken by Macready, who reached a height of 10,519 meters (34,510 feet).

Penetrating the stratosphere

Not only do airmen reach great heights, but they fly faster than and have endurance exceeding that of the largest birds. They have remained aloft for a period of thirty-six hours, and doubtless will soon be able to surpass this. Speeds of 100 meters per second and more have been made. General Mitchell, flying at Selfridge Field, October 18, 1922, flew down the wind at a speed of 108 meters per second, or 244 miles an hour;

Endurance and velocity tests

FIG. 3. CIRRUS. FOLLOWED BY RAIN WITHIN FIVE HOURS

while the speed up wind was 91 meters per second, or 205 miles an hour. The fastest cloud ever measured does not exceed this speed; and those of a stormy day do not travel one-fourth

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as fast. The maximum airplane speed over one kilometer is 236.6 miles per hour, made by Lieutenant R. L. Maughan, U. S. A., March 29, 1923, exceeding the record of Sadi

FIG. 4. THE TOP OF CLOUDLAND. CIRRUS

Lecointe, of France, 233 m. p. h. The maximum speed over 1000 kilometers is 127 m. p. h. Lieutenants Macready and Kelly flew from Roosevelt Field to San Diego in 26 hours, 50 minutes, without untoward incident, May 2, 1923.

Records at Blue Hill Observatory, where observations have been in progress for nearly forty years, show that the highest or cirrus clouds move about 45 meters per second, 100 miles an hour. To be somewhat more precise: at the top of the cloudland, that is, at a height of 10,000 meters, the average velocity of the clouds is 46 meters per second. But more than 70 per cent of the clouds occur below 3000 meters, and these have a velocity of 20 to 30 meters per second.

Cloud velocity

The highest speed thus far determined is that of a cirrus cloud that sped across the sky at 102.6 meters per second—228 miles per hour. Speeds of 100 meters per second are rare, but speeds of 80 to 90 meters per second are not infrequent.

A natural deduction from what precedes is that, if we combine the speed of a fast flyer with the speed of a high cloud, the total speed will be the sum of the two; and we might, therefore, expect a final speed of 400 miles an hour. Such a velocity approximates 10,000 miles per day; and hence an airman could travel around

Airplane velocity

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the world at the equator in less than three days; or if by way of New York, London, Tokyo, Seattle, and Chicago, in less than two days.

But all speeds are relative; and while the speed of the cloud is relative to the ground, as is also the speed of the plane, the speed of the latter, relative to the air in which it is immersed, is a different matter. Moreover, the density of the air is considerably less at high elevations, being in fact at 10,000 meters only one-third of the surface density. But this and other difficulties have been overcome with compressor devices, and the speed of the plane made practically the same as when in lower air. It is almost feasible now to cross the Atlantic in a day; and doubtless before long the real hustling type of business man will breakfast in New York and have his late supper in London.[1]

FIG. 5. CLOUD MASS AT CLOSE RANGE. BOTTOM OF STRATUS

[1]Attempts to travel from New York to San Francisco between sunrise and sunset have been made by the Army Air Service (Lieutenant Maughan), but, owing to mechanical trouble, have not yet succeeded.

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FIG. 6. THE HIGHEST CLOUD. CIRRUS

2. Classifying the clouds. No one seems to have attempted to classify the clouds until the beginning of the nineteenth century. Then Lamarck, in 1801, described certain types; and in 1802 Luke Howard, a young chemist of Tottingham, London, proposed a system which was accepted and used without change for more than a hundred years. Lamarck was not particularly successful as a meteorologist, and it is said that Napoleon was often sarcastic at his expense. Howard was very fortunate. His work was acclaimed at home and on the Continent as worthy of great praise. Goethe wrote him many laudatory letters, which read today seem to be extravagantly phrased.

Classifications of Lamarck and Howard

The weakness of Howard's classification is that it is based entirely upon appearance or form, not on origin, formation, or significance. He made three prime divisions: the layer cloud, the lump cloud, and the curl cloud. If now we use the Latin equivalents for these types, we have *stratus*, *cumulus*, and *cirrus*. Add also the Latin word for fog or cloud, *nimbus*, which really means a cloud without form, but restrict the meaning to rain; and we have the essentials of the system.

From these four basic types, Howard made several combinations, such as strato-cumulus, cirro-cumulus, and cirro-stratus. The strato-cumulus type is perhaps the most frequently seen of all cloud forms.

The word *fracto* (not used by Howard) is now in general use to designate a cloud form in which the mass is broken into small divisions. Thus we have fracto-stratus, fracto-cumulus, and fracto-nimbus.

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3. The international cloud classification. In 1890 there was a conference of meteorologists from various countries and an attempt was made to establish an international cloud classification. Ten types were agreed upon, and arranged in three major and two minor levels. Beginning with the highest, the cirrus type, at an elevation of 9000 meters (5.6 miles or 29,500 feet), we drop down to an intermediate level 7000 to 3000 meters (23,000 to 10,000 feet), where we find cirro-cumuli, alto-cumuli, and nimbus clouds. Thus the atmosphere may be likened to a three-story edifice, but with two mezzanine floors

Ten types of clouds

FIG. 7. CURTAINS OF THE COMING NIGHT. CIRRUS

or entresols for the accommodation of high fogs and certain clouds due to diurnal ascending currents. The high fogs and stratus lie below the 1000-meter level; while the cumuli and cumulo-nimbus may have their bases 1500 meters above the ground and their tops from 3000 to 9000 meters above their bases. The ten types are as given on pages 9–13.

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1. *Cirrus* (Ci.). Isolated feathery clouds of fine fibrous texture, generally of a white color, frequently arranged in bands which spread like the meridians on a celestial globe over a part of the sky and converge in perspective toward one or two opposite points of the horizon. In the formation of such bands Ci.S. and Ci.Cu. often take part.

FIG. 8. CIRRUS NEBULA

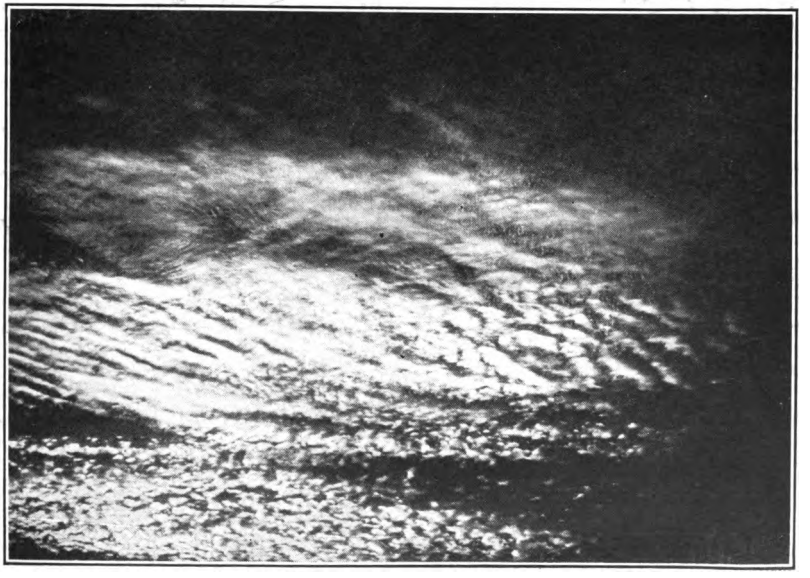

FIG. 9. CIRRO-CUMULUS. SOMETIMES CALLED SPECKLE CLOUD

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FIG. 10. WHIRLING ALTO-STRATUS

2. *Cirro-stratus* (Ci.S.). Fine whitish veil, sometimes quite diffuse, giving a whitish appearance to the sky, and called by many "cirrus haze," sometimes of more or less distinct structure, exhibiting tangled fibers. The veil often produces halos around the sun and moon.
3. *Cirro-cumulus* (Ci.Cu.). Fleecy cloud. Small white balls and wisps without shadows, or with very faint shadows, which are arranged in groups and often in rows.
4. *Alto-cumulus* (A.Cu.). Dense fleecy cloud. Larger whitish or grayish balls with shaded portions grouped in flocks or rows, frequently so close together that their edges meet. The different balls are generally larger and more compact (passing into S.Cu.) toward the center of the group, and more delicate and wispy (passing into Ci.Cu.) on its edges. They are very frequently arranged in lines in one or two directions.

   The term "cumulo-cirrus" is given up because it causes confusion.
5. *Alto-stratus* (A.S.). Thick veil of gray or bluish color, exhibiting in the vicinity of the sun and moon a brighter portion, which,

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without causing halos, may produce coronas. This form shows gradual transitions to cirro-stratus, but according to the measurements made at Upsala it is only half the altitude.

The term "stratus-cirrus" is abandoned because it gives rise to confusion.

6. *Strato-cumulus* (S.Cu.). Large balls or rolls of dark cloud which frequently cover the whole sky, especially in winter, and give it at times an undulated appearance. The stratum of strato-cumulus is usually not very thick, and blue sky often appears in the breaks through it. Between this form and alto-cumulus all possible gradations are found. It is distinguished from nimbus by the ball-like or rolled form and by the fact that it does not tend to bring rain.
7. *Nimbus* (N.). Rain clouds. Dense masses of dark, formless clouds with ragged edges, from which generally continuous rain or snow is falling. Through the breaks in these clouds is almost always seen a high sheet of cirro-stratus or alto-stratus. If the mass of nimbus is torn up into small patches, or if low fragments of cloud are floating much below a great nimbus, they may be called "fracto-nimbus," the "scud" of the sailors.
8. *Cumulus* (Cu.). Wool-pack clouds. Thick clouds whose summits are domes with protuberances, but whose bases are flat. These clouds appear to form in a diurnal ascensional

FIG. 11. LOW STRATO-CUMULUS SAILING BEFORE A WEST WIND

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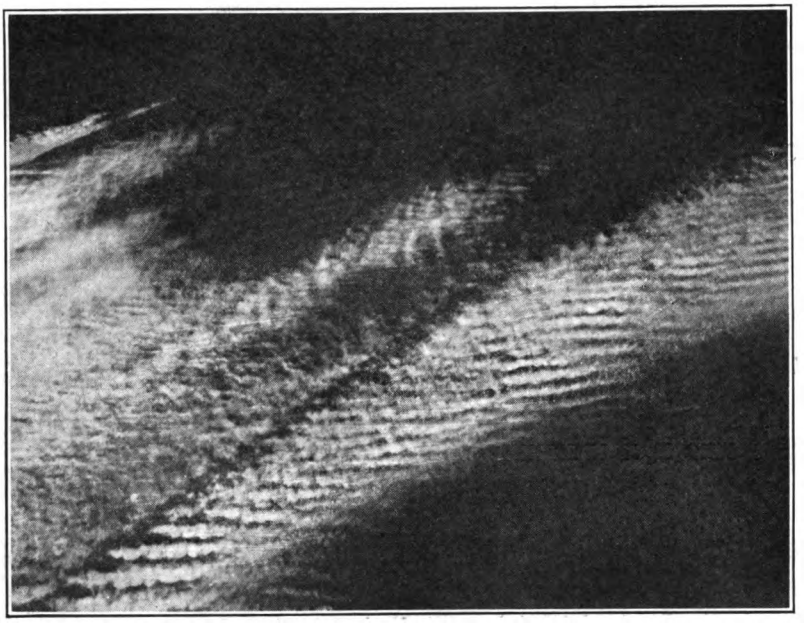

FIG. 12. HIGH ALTO-CUMULI. THE HERRING BONE

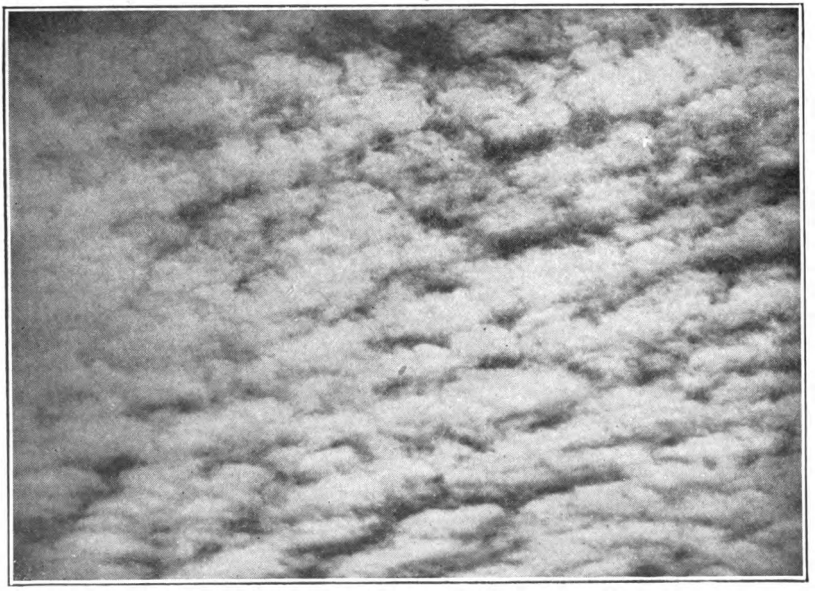

FIG. 13. ALTO-CUMULI. THE WOOL PACK

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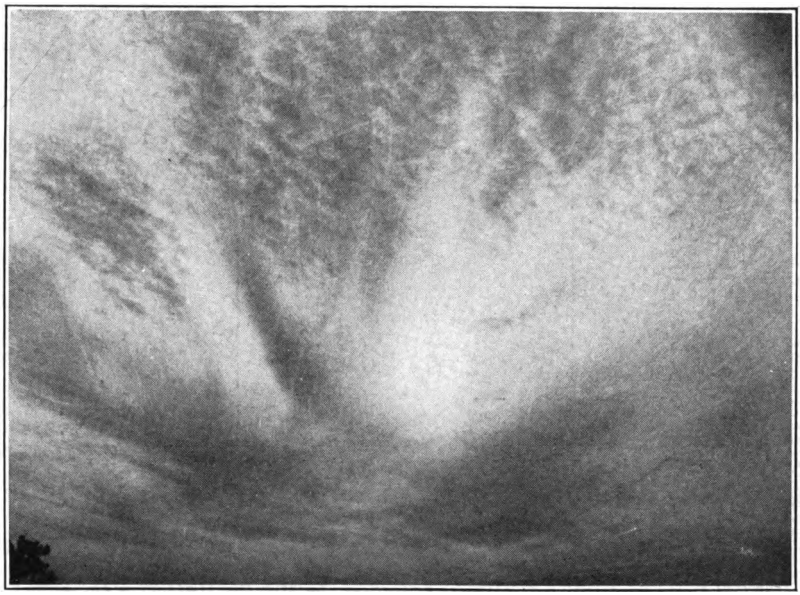

FIG. 14. TRANSFORMING ALTO-CUMULI. PRECEDING RAIN

movement, which is almost always apparent. When the cloud is opposite the sun, the surfaces which are usually seen by the observer are more brilliant than the edges of the protuberances. When the illumination comes from the side, this cloud shows a strong actual shadow; on the sunny side of the sky, however, it appears dark with dark edges. The true cumulus shows a sharp border above and below. It is often torn by strong winds, and the detached parts present continual changes ("fracto-cumulus").

9. *Cumulo-nimbus* (Cu.N.). Thunder cloud; shower cloud. Heavy masses of clouds, rising like mountains, towers, or anvils, generally surrounded at the top by a veil or screen of fibrous texture ("false cirrus") and below by nimbus-like masses of cloud. From their base generally fall local showers of rain or snow and sometimes hail or sleet. The upper edges are either of compact cumulus-like outline, and form massive summits, surrounded by delicate false cirrus, or the edges themselves are drawn out into cirrus-like filaments. This last form is most common in "spring showers." The front of thunderstorm clouds of wide extent sometimes shows a great arch stretching across a portion of the sky, which is uniformly lighter in color.
10. *Stratus* (S.). Lifted fog in a horizontal stratum. When this stratum is torn by the wind or by mountain summits into irregular fragments, the clouds may be called "fracto-stratus."

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CLAYTON'S CLASSIFICATION OF CLOUDS ACCORDING TO ALTITUDE [1]

Levels	Average altitude	Most frequent altitudes	Stratiforms	Cumuliforms	Flocciforms	Cirriforms
	meters	meters				
Stratus.....	500	600	Stratus (S) Nimbus (N) Fracto-stratus (fs) Fracto-nimbus (fN)	Cumulus *informis* (Ki)		
Cumulus.....	1600	1200 to 1700	Alto-nimbus (aN)	Cumulus (K)	Nimbus *cumuliformis* (NK)	
Alto-cum.....	3800	3000 to 4400	Alto-stratus *nimbiformis* (Asn) Alto-stratus (As)	Cum-nim. (KN)	Strato-cumulus (SK) Alto-cum. (AK) Alto-cum. *tenuis* (AKT)	
Cirro-cum	6600	5800 to 7200	*Velo*-cirro-strat. (Vcs) *Velo*-cirro-strat. (Vcs)		Cirro-cumulus (CK) *Grano*-cirro-cum. (gCK)	
Cirrus.....	8900	8500 to 10000	Cirro-stratus (Cs) *Lacto*-cirro-strat. (lcs)		*Flocci*-cirrus (flC)	Cirrus (C) Cirrus (C)

The letter "K" is used to indicate cumulus.

The average altitudes given in the first column of figures for each level were determined by direct measurements made at Blue Hill Observatory by Rotch, Clayton, Fergusson, Sweetland, and Wells. The *level* was recorded in each case from observation, and the altitudes were afterward computed from angular measurements made at the same time with theodolites. This shows the possibility of distinguishing the five levels.

[1] From *Principles of Aërography*, page 119.

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VARIOUS CLOUD NAMES

4. Latin terminology. The only reference which Shakespeare makes to our western world is, strangely enough, associated with rain. In some way unknown to commentators he heard of the Bermudas. In *The Tempest* he makes the clown, watching a cumulo-nimbus cloud, speak of it with fear and trembling: "A foul bombard . . . . yonder same cloud cannot choose but fall by pailfuls."

Need for simpler terminology

The immortal bard of Avon was fully aware of the picturesque side of cloud forms. He speaks in *Antony and Cleopatra* of

> A cloud that's dragonish;
> A vapor sometimes like a bear or lion,
> A towered citadel.

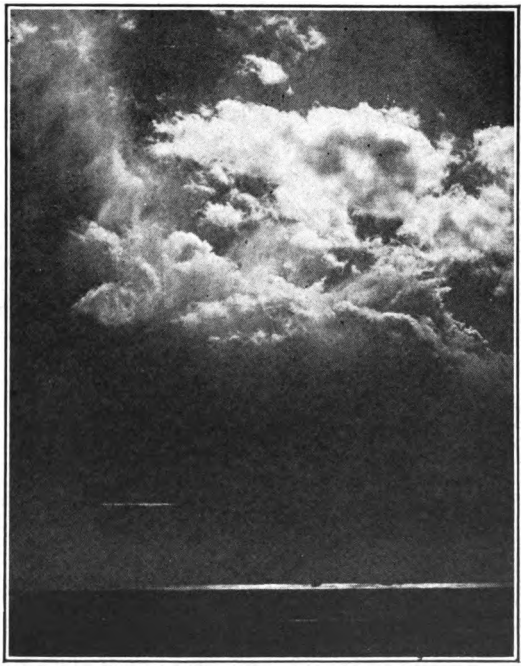

FIG. 15. EDGE OF DISSOLVING CUMULUS

Instead of these simple descriptions, the modern cloud sharp would substitute for "dragonish," *cumulus horribilis;* for "bear," *stratocumulus ursus;* and for "towered citadel," *cumulo-nimbus-castellatus.* These rather long terms seem unnecessary. They make us think of Huxley's remark that if one had to mention a *great-beastium* he could achieve a reputation for erudition by calling it a *megatherium.* More than one hundred of these Latin names have been seriously proposed. On page 16 we give a few with the equivalent meaning.

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FIG. 16. CURLED ENDS OF CIRRO-STRATUS

SOME LATIN CLOUD NAMES, WITH ENGLISH EQUIVALENTS

Pallio-cirrus or sheet cirrus
Fracto-cumulus or broken cumulus
Globo-cirrus or knob cirrus
Gibbo-cirrus or hump cirrus
Cirrus-uniformis or cirrus in one piece
Cirrus-caudatus or tailed cirrus bands
Fracto-cirrus or broken cirrus
Cirrus-filosus or thread cirrus
Cirrus-pendulus or cirrus fibers beneath
Cirrus-undulatus or wave cirrus
Cirrus-adhaesus or cirrus fibers above
Cirrus vertebratus or vertebrate cirrus
Cirrus-equinus or mare's tails
Cirrus-pennatus or plumed
Cirrus-reticulatus, reticulated or netted
Cirrus-diffusus or diffused cirrus
Cirrus-rotundus or rounded cirrus
Cirrus-extensus or far-spread cirrus
Cumulus-precipitans or rain from a cumulus
Cumulus-mammatus or mammato-cumulus; hanging down like breasts
Alto-stratus-tonitras or thundering clouds
Cumulo-nimbus grandineus or hail rain clouds

There is urgently needed a classification of clouds which will tell of the origin of the cloud and its life history. When

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we look at a cloud we want to know, not what it resembles, but whether it portends fair or foul weather. It should be an index of the flow of air and the behavior of the water vapor. It must be admitted that present names do not help us much, and we are left in ignorance of that which we should most like to know, namely, the significance of cloud life in connection with impending weather.

5. Distribution of clouds. The most comprehensive study of cloud formation and distribution is that attempted by the International Cloud Commission May 1, 1896, to July 1, 1897. Professor F. H. Bigelow, representing the United States, has given with great detail the movements of the clouds.

Bigelow's report

One of the most interesting diagrams is that showing the distribution of the clouds during the various months, giving also mean heights and frequencies. See Fig. 17, page 18, and Fig. 18, page 19, which are reproduced from *Principles of Aërography*, pp. 120 and 122. The general distribution of cloud direction and velocity at an elevation of 1000 meters, also the surface winds, are shown in Fig. 19, page 20. The length of the arrow is proportional to the velocity. As a rule the velocity at 1000 meters is twice the velocity at the surface.

Four charts (Figs. 20–23) taken from Bigelow's report show the general directions and velocities over the United States when a disturbance, that is, an area of low pressure, is centered over New England in winter; also the directions and velocities when a "high" or anticyclone is thus centered. The very high clouds, like the cirrus and cirro-stratus, move quite uniformly from the west.

The sequence of cloud types in advance of a storm begins with a layer of cirrus-stratus moving rather rapidly from the west or west-southwest. These clouds frequently result in solar (or lunar) halos. The ice crystals, hexagonal thin plates and needles, when properly oriented refract the light. The most common halo has a radius of 22° with the inner edge reddish and the outer edge greenish yellow. Occasionally a halo of larger radius 46° is seen; but as a rule it is indistinct and colorless.

Cause of halos

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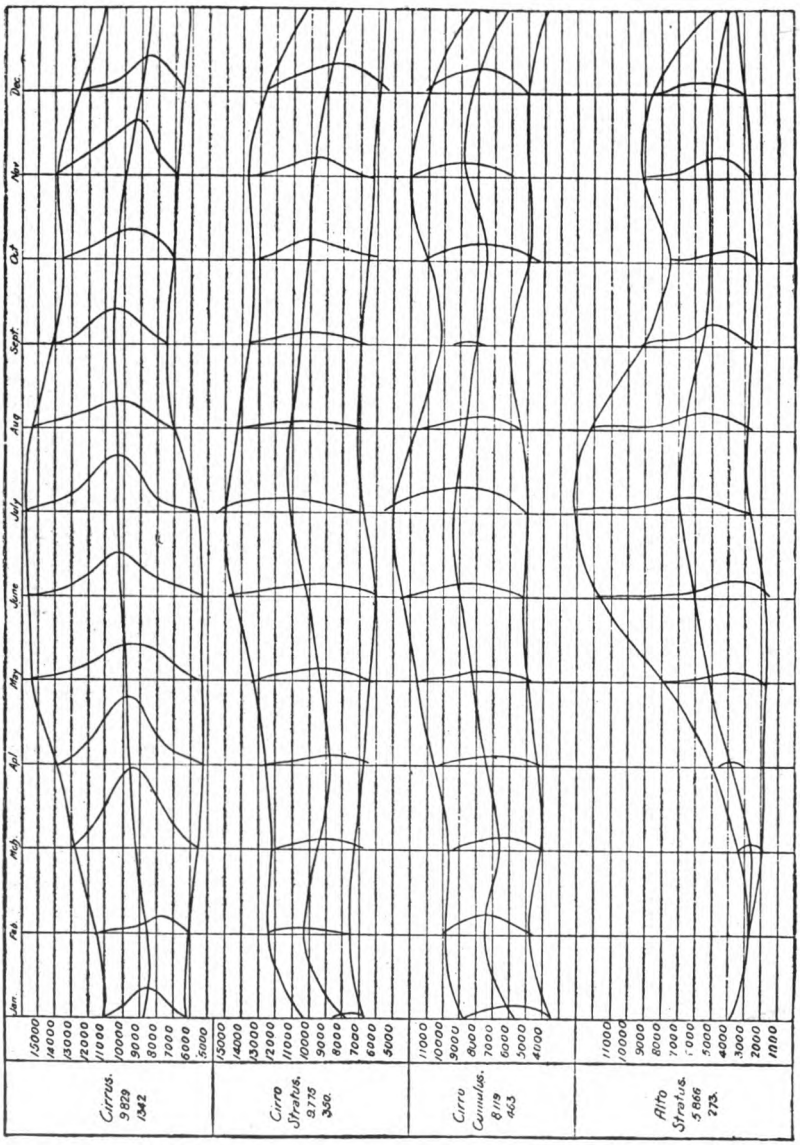

FIG. 17. DISTRIBUTION OF CLOUD TYPES. UPPER CLOUD

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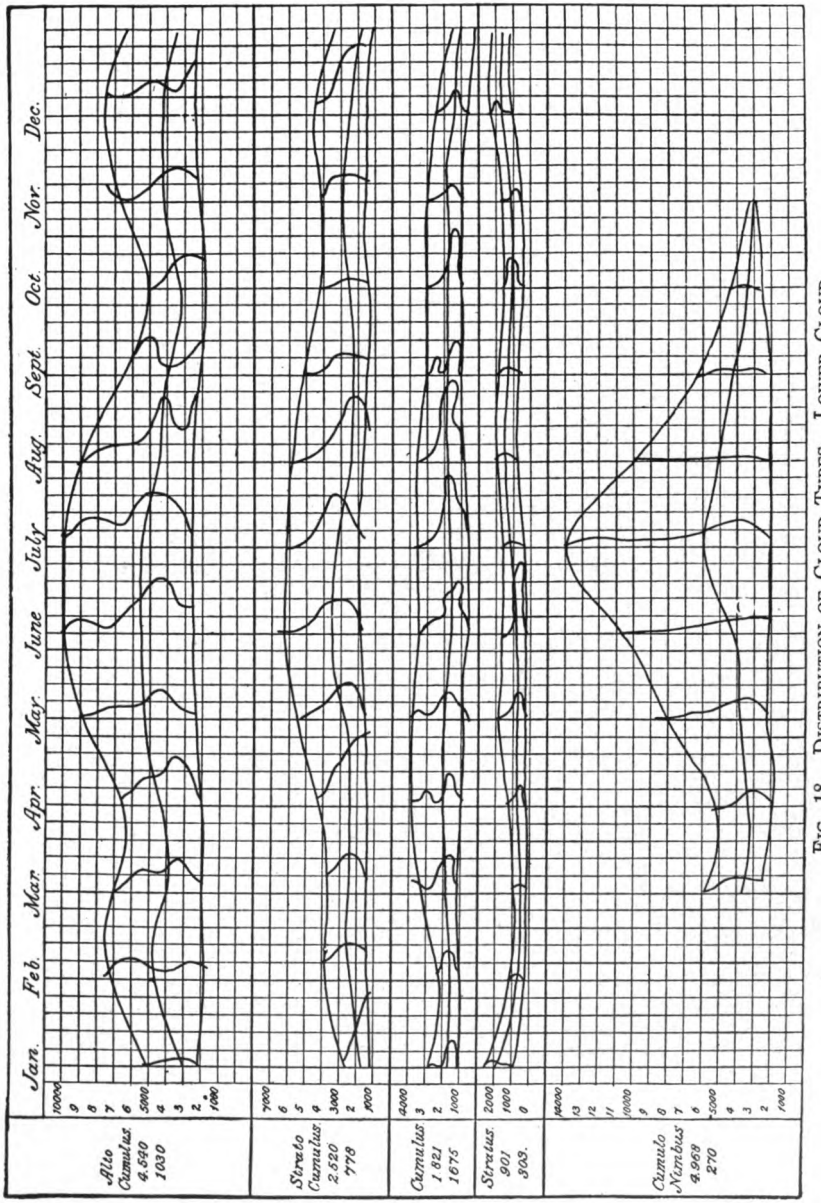

FIG. 18. DISTRIBUTION OF CLOUD TYPES. LOWER CLOUD

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Parhelia and paraselenae

Mock suns (parhelia) and mock moons (paraselenae) are sometimes seen and are bright spots generally in the halo of 22°, where the mock sun ring intersects the halo. The edge nearest the sun is red. Occasionally vertical shafts of light known as sun

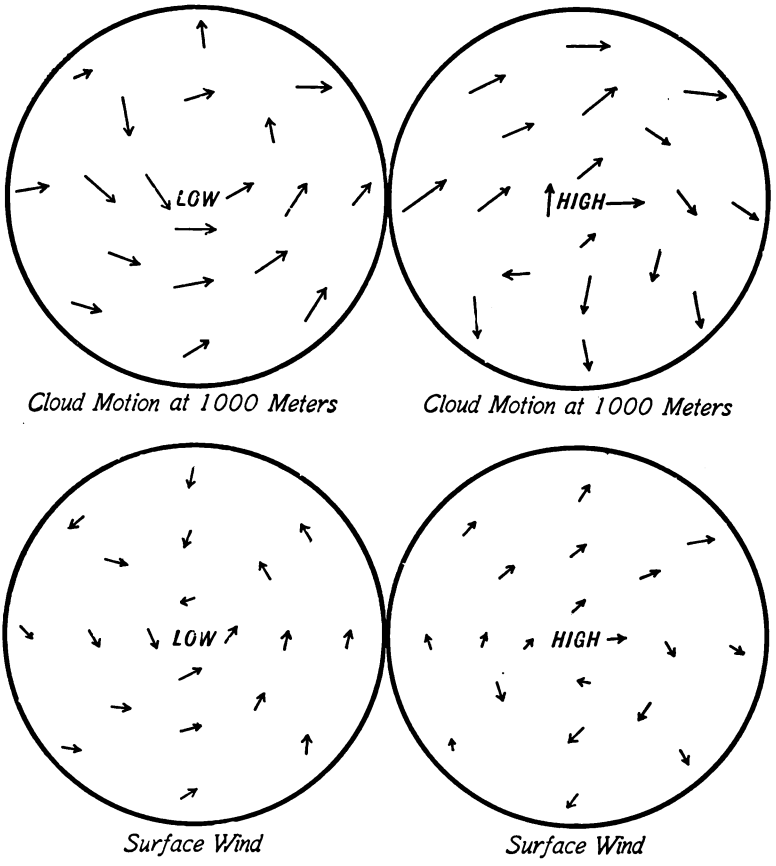

FIG. 19. FLOW OF AIR AT SURFACE AND AT 1000 METERS IN "LOW" AND "HIGH"

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pillars are seen when the sun is near the horizon. All of these optical phenomena are connected with the presence of cirro-stratus clouds. These are quite different from the slants of light known popularly as the "sun drawing water."

Sun pillars

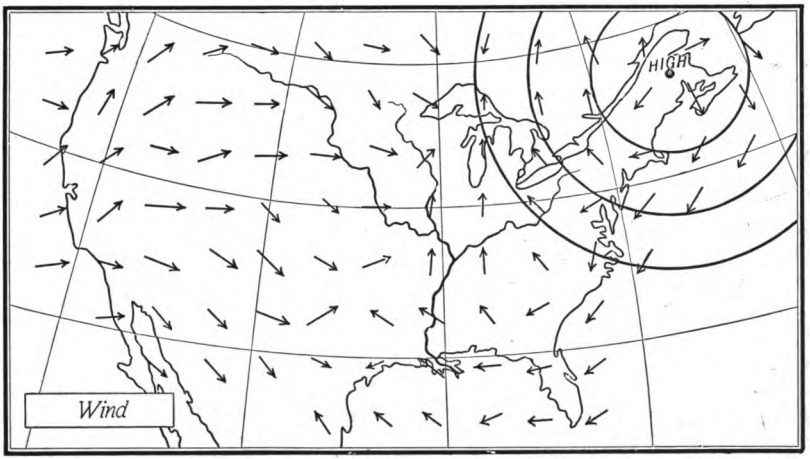

FIG. 20

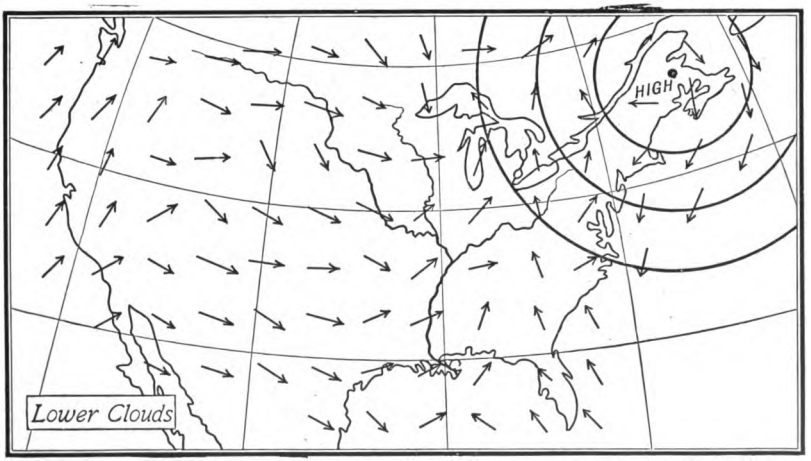

FIG. 21

FIGS. 20, 21. SURFACE WINDS AND LOWER CLOUDS WHEN AN ANTICYCLONE IS CENTERED OVER NEW ENGLAND

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With clouds of a lower level, not essentially ice-crystal clouds, colored circles of much smaller radius, about 4°, are often visible. These are known as coronas or "glories." The order of the colors is the reverse of that in halos, the red being now on the outside. This is due to diffraction of the light. There is sometimes a double or even triple circle, the outer one having a radius of 8°.

Coronas

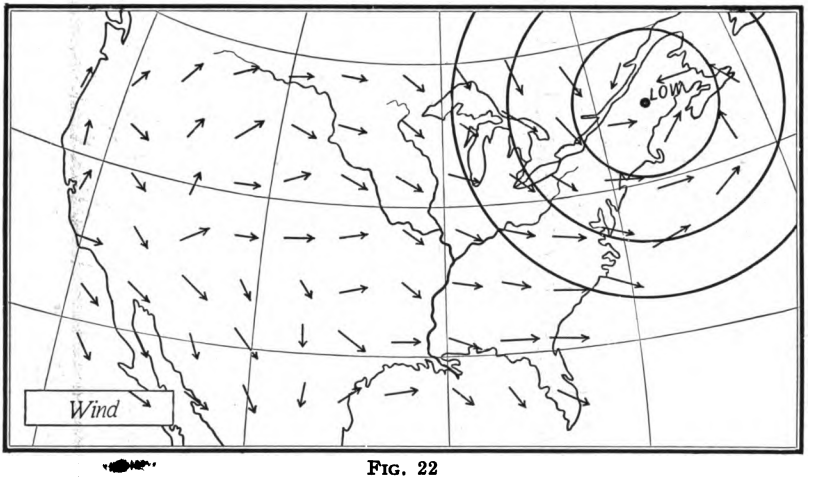

FIG. 22

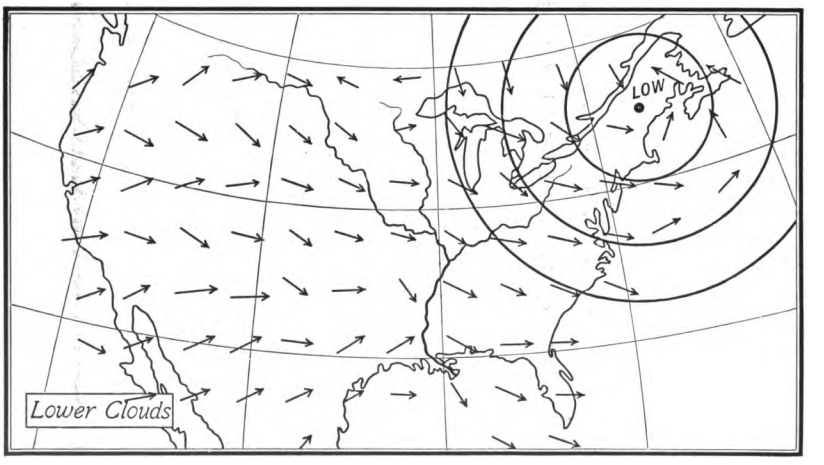

FIG. 23

FIGS. 22, 23. SURFACE WINDS AND LOWER CLOUDS WHEN A DEPRESSION IS CENTERED OVER NEW ENGLAND

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The cirro-stratus and cirro-cumulus give way within an hour or two to denser lower clouds, such as alto-stratus and certain strato-cumulus types. Strato-cumulus clouds sometimes

FIG. 24. SUNBEAMS SLANTING THROUGH LOWER CLOUDS

assume a lenticular form a few hours preceding rain. Finally, with the nimbus cloud we have the falling rain or snow.

The sequence given above holds for cyclonic rains, or rains due chiefly to horizontal movement of the air masses. There is another type of rainfall, that of the summer afternoon shower, in which the condensation is primarily the result of ascending air. This is well shown by the building up of cumulus and cumulo-nimbus clouds.

Rainbows, generally seen at times of such showers, are due to both refraction and reflection of the sun's rays by the raindrops. In a primary bow the inner edge is violet and the colors are those of the spectrum, with red on the outside. In a secondary bow the order is reversed, because there have been two reflections preceding the last refraction. Inside the primary bow, there sometimes can be seen faint narrow bands. These are known as the supernumerary bows.

Rainbows

It is not easy to explain refraction phenomena, especially the deviation of rays through water drops, without going extensively into atmospheric optics. Elaborate discussions of these light phenomena are given in Exner's *Meteorologische Optik;* Mascart's *Traité d'Optique*, and Humphrey's *Physics of the Air.*

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RAIN MAKING

6. Can we make rain? So much has been said in preceding sections with regard to man's achievements that one naturally asks, "Will it ever be possible to make rain?" It is indeed possible now to make rain and even snow in small quantities and over very limited areas. Thus in a railway terminus on a winter day, the rising steam from many locomotives, provided certain conditions of humidity and temperature-decrease prevail, may be seen either to condense as raindrops or to crystallize into snowflakes.

But what men want to know is: "Will it ever be possible so to act upon the free-floating clouds that rain will fall on the fields or wherever needed?" An even more important desideratum is: "Can we make it stop raining when enough rain has fallen?"

This indeed is important; for the floods do more damage than the droughts.

But the attention of men will ever be directed toward the first problem, that of making rain. For every time a drought occurs men feel the need of water. Shortage of water affects every industry, and at such times any suggestion of an agency for the production of rain will appeal to the imagination of the public.

Importance of rain

In dry countries water is valued and often conserved; but in districts where rains are normally frequent, departure from usual climatic conditions causes comment and uneasiness.

Hence during the drought of 1921 in Great Britain the question was asked in the House of Commons whether the government was prepared to initiate rain-making experiments. The reply of the Ministry was that there was no reason to believe that rain could be produced artificially. Some experiments, sponsored by a leading newspaper, were made, chiefly by exploding small charges and using rockets, and also by spraying liquid air on the clouds. There were no apparent results.

Rain-making experiments

The drought was a memorable one and its causes will be referred to later, as will also the conditions which favored, if they did not indeed bring about, the cessation of the dry spell.

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There are some localities where rainfall is confined to a definite period of the year. Generally the winter is a wet season and the summer a dry period. In California, for example, little or no rain falls between June and October; but the winter months have frequent and more or less heavy rainfalls. During February, 1920, a month usually wet, there was practically no rain. It was woefully dry, and this at a time when the water necessary for storage to meet the long, dry summer was expected. Naturally at such a time the rain maker bulks

Variations in periodic rainfall

FIG. 25. FORERUNNER OF THE RAIN. COOLING BY MIXTURE

large in the public eye; and his efforts are exploited by the press. But here, as always before, claims and results were wide apart. None of the rain makers who have thus far come into prominence has been trained in physics nor given evidence of a knowledge of aërography—the science of the structure of the air. It has not occurred to any of them that changing vapor of water into liquid water sets free much heat—for every gram, 536 calories. Or put it this way: It takes much heat energy to vaporize a gram of water. If the process is to be reversed, a considerable volume of vapor must be condensed before one small raindrop can be produced. The ratio is something like 1674 to 1.

Heat in relation to vaporization

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The rain maker has thus far failed to estimate properly the dimensions of the quantities involved. He is like the child on the beach trying to drain the ocean with a very small pail.

Quantity of water in the air

In a moderately heavy rain the total quantity of water in a cubic meter of space will not weigh more than a gram, so that only a few drops can be forced out of a fairly large block of air; hence even a good-sized cloud, which, however, is a mass mixture of air and vapor, may yield but a small quantity of rain. Heavy and continued rains indicate a vast air stream, carrying a heavy load of water vapor, and all subjected to cooling, by

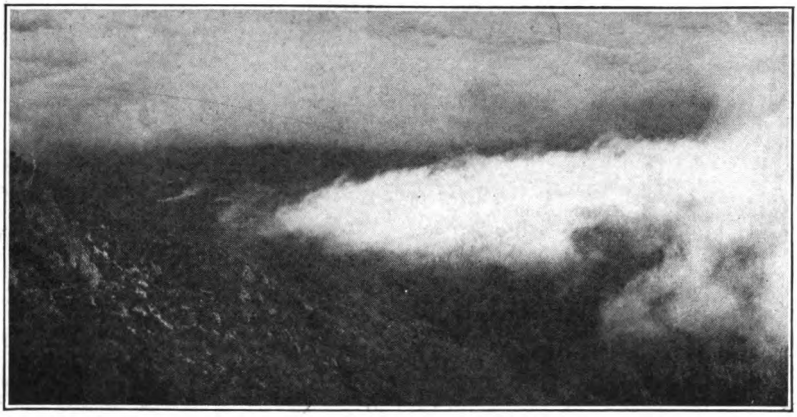

FIG. 26. VALLEY FOG. TYPE DESCRIBED BY STEVENSON IN "SILVERADO SQUATTERS"

lifting causing expansion, or by contact with cooler surfaces, or by mixing with a cooler air stream, or by extremely rapid loss of heat owing to intense radiation. With moderate cooling the vapor becomes visible as cloud or fog; if the cooling is rapid, raindrops are formed. If the cooling is prolonged and below freezing, snowflakes are formed. Moreover, there must be a surface to condense on. Mere cooling is not enough.

Water does not change at once to steam at the boiling-point temperature, nor to ice at the freezing point. Neither does vapor change back to water immediately on cooling to the condensing-point temperature so called. There must be

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further cooling and a free surface. The free surface must be subcooled. He who would make rain should first study the making of a drop of dew. Close watching will show many unexpected relations.

The rain maker might also take heed of another fact; namely, that the process of making a drop of dew goes on without much noise. There is no shooting of cannon, no rending of the air by explosions. On the contrary, there is neither tumult nor turmoil. Indeed, even a little stirring of the air will work against the formation of dew or frost. On windy nights when the air is churned thoroughly, there is no dew. The belief in the efficacy of concussion arose, as we shall mention later, from an erroneous opinion that battles produced rain; also perhaps from the fact that after a violent thunder clap there is often a gush of rain. This will be described in detail later.

Efficacy of concussion in rain making

7. Some near cloud makers. The nearest real rain maker is a subcooled blade of grass. Given a sufficient absolute humidity and the necessary fall in temperature, there results a drop of liquid, not exactly at the top of the blade, but nearer the ground. The nearest cloud maker is one's own self. All men are created cloud builders. We exhale a stream of air that is warm and moisture-laden. The water vapor in this expired breath will condense if cooled to the dew point. We do not always see our breath, but on winter mornings nothing is more common. The temperature of the mixture as it leaves the mouth is 1134 (97.7° F.), but the air outside may be at freezing temperature or even down to zero Fahrenheit. Hence a cooling of 200 Kelvingrads. This means that the breath, holding 43 grams of water, goes into an atmosphere where a single gram saturates it. Hence a relatively large quantity of water vapor, which was invisible, suddenly becomes visible. As the normal rate of breathing is about 16 per minute and the volume of air expired small, the weight of the water in a single breath is but a fraction of a gram.

Man as a cloud builder

Incidentally notice that when we cease cloud making we cease to live.

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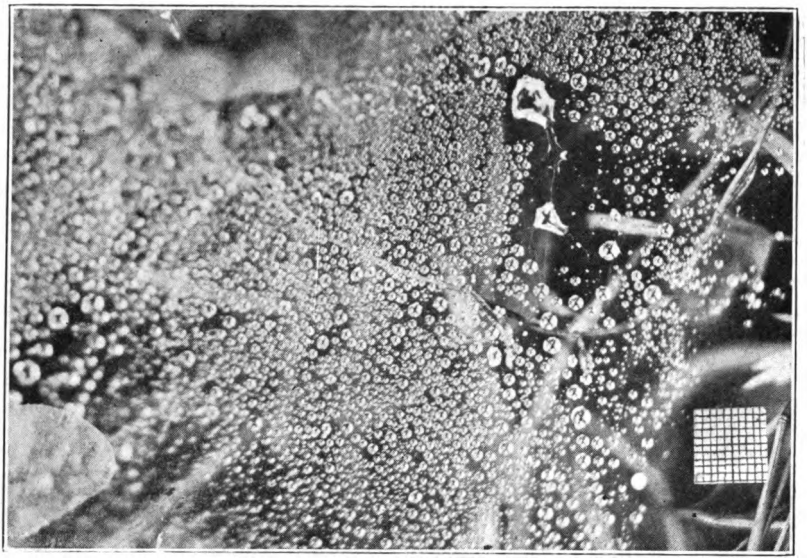

FIG. 27. DEWDROPS ON A GOSSAMER. ACTUAL SIZE

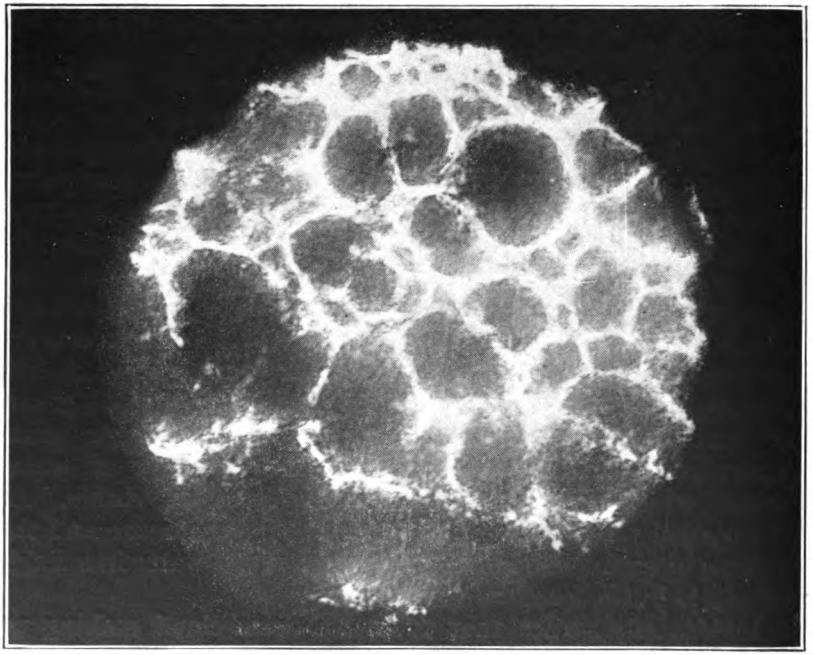

FIG. 28. DEWDROP ON A GOSSAMER. MAGNIFIED FIFTY DIAMETERS

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The human body may also be likened to a wet-bulb thermometer; or better, as Dr. Leonard Hill of London, who has done so much work measuring humidity and body loss of heat, calls it, a katathermometer, an instrument measuring loss of heat. The skin is the evaporating surface; and, while we can hardly call the sweat glands rain makers, yet, when perspiration is present, there follows evaporation and skin cooling, or else extreme discomfort. If there is much water vapor in the air, as on a muggy day, a condition known as saturation, the rate of evaporation is much less than on a dry day. This explains the discomfort of certain warm moist days, the dog days, when newspapers feature high humidity. In one sense this is wrong, for we can have high relative humidity on a cold day.

Saturation as affecting evaporation

What the press should feature as the primary cause of discomfort and physical suffering on muggy days is the *absolute humidity*. The data usually published showing relative humidity have no real value as indicating the source of the suffering. This can be made plain by an example. On a certain day in July the temperature is in the nineties; and the relative humidity is 90, which means that the air is nearly saturated. On such a day perspiration does not evaporate rapidly, and there is much suffering. Another day may have a temperature as high or even higher, but if there is less water vapor present, say 20 grams per cubic meter of space as against 30 grams on the muggy day, the perspiration does rapidly evaporate and, because of this skin cooling, we feel more comfortable, although the temperature may be higher. So, then, it is a question of evaporation of the water on the skin, brought there by the sweat glands. And the rate of evaporation varies with the *absolute* humidity.

Relative and absolute humidity

8. Sea fog. Let us now study cloud building over the ocean—the first step being the formation of fog.

We are all familiar with the fog banks off Newfoundland, where a great river in the ocean, known as the Labrador Current, sweeps southward. Another great river in the ocean, one which Commodore Maury loved to write about—the Gulf Stream—pushes northward along

Ocean currents

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the Florida coast to the Jersey coast and then, forced eastward, fans out into a wide but shallow stream.

Formation of fog

Let us study the logs of steamships as they plough northward. We find many reports of fog-forming in Hydrographic Office circulars. One will serve. On February 16, 1922, the good ship "Munargo" was steaming north, off Cape Hatteras. As it was crossing the Gulf Stream a heavy vapor suddenly covered the sea. At times this fog was so dense that the captain could not see the bow of the ship from the bridge. Analyzing the conditions, we find that a cold brisk wind, indeed a gale, was blowing from the north. This stream of air came from New York and New England, where the temperature, we know, was far below freezing. It was in fact the coldest day of the winter. The ship, plunging northward through the Gulf Stream, was in warmer water, actually 1083 kilograds (72° F.). So there was quick cooling of the warm vapor. In every cubic meter there was enough vapor to make 50 ordinary raindrops if *entirely* condensed. As soon as the ship passed out of the Gulf Stream, the fog disappeared.

The process of fog-making or rendering visible otherwise invisible water vapor may be studied to great advantage at

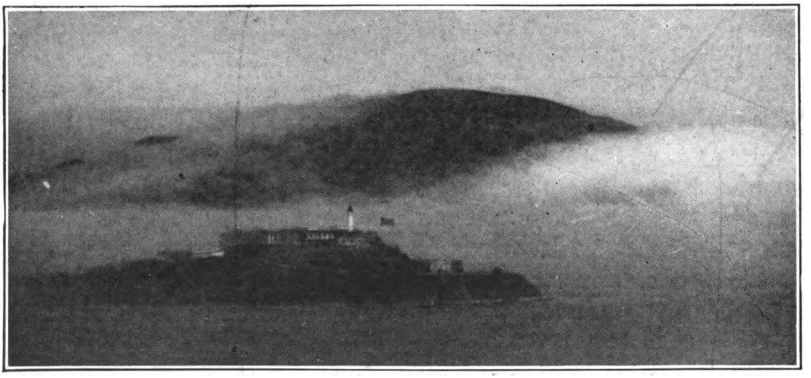

FIG. 29. SEA FOG FORMING AND DRIFTING

the entrance to the Bay of San Francisco. On summer afternoons the fog forms outside, drifting in through the Golden Gate. How is it formed?

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There is an upper air stream moving west which is brought down to the ocean level and cooled. The fall in temperature amounts to 30 kilograds, 15 Fahrenheit degrees. The vapor

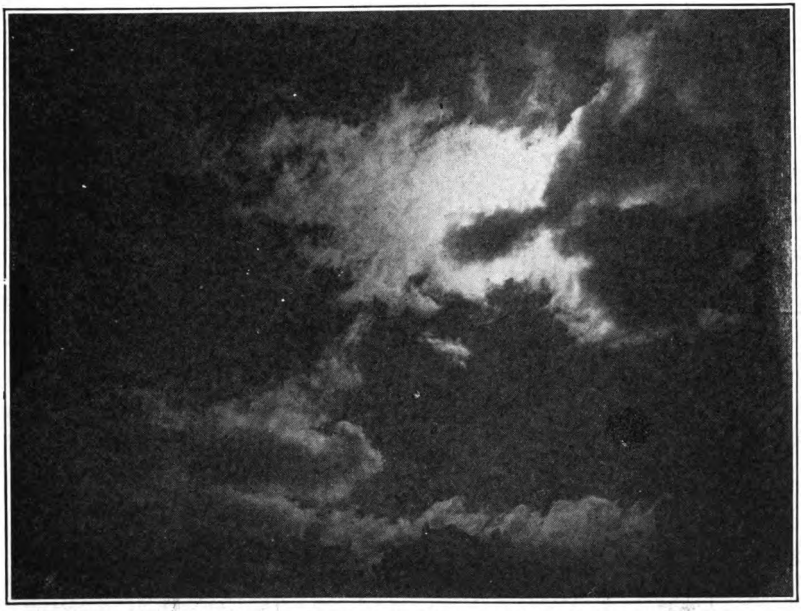

FIG. 30. FOG RISING AND CHANGING INTO FREE FLOATING CLOUD

condenses and a fog bank forms which is carried in through the Gate by the surface wind moving east. It soon, however, comes into a warmer atmosphere and disappears over the Contra Costa Hills. The vapor, now invisible, rises over the Great Valley. At a height of 1000 meters the air turns again westward and the vapor, still invisible, is carried out to sea. The current does not go far, however, and slopes gradually downward. Nearing the ocean surface, the vapor is sharply cooled and condensed.

Thus we have a circle, but not a vicious one, for the fog cools the cities around the Bay. In this circuit the vapor appears, disappears, and reappears only to disappear again. Not inaptly may the whole operation be described as Nature's thwarted effort at rain making. (For illustration, see Fig. 1, facing page 1.)

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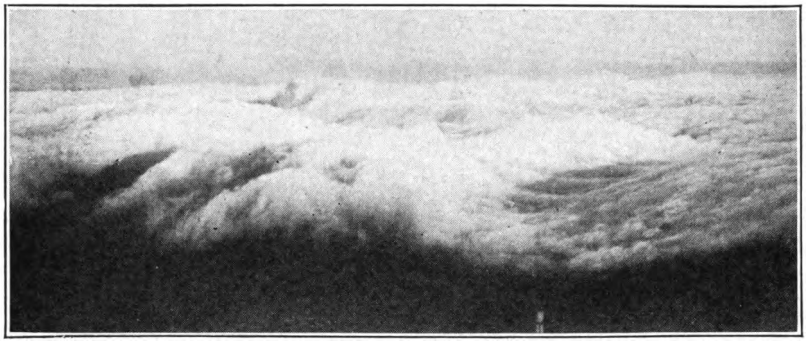

FIG. 31. HOW THE WIND RUFFLES THE FOG NEAR THE GOLDEN GATE

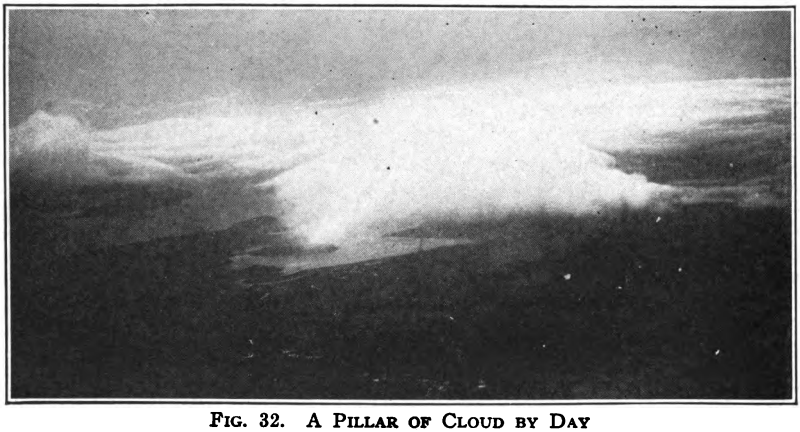

FIG. 32. A PILLAR OF CLOUD BY DAY

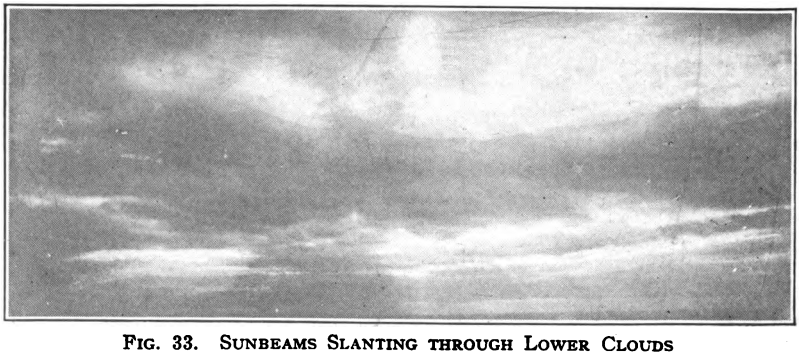

FIG. 33. SUNBEAMS SLANTING THROUGH LOWER CLOUDS

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9. Artificial versus natural rain makers. Thirty years ago there was much discussion in scientific circles as to the possibility of rain making by the use of explosives. The Congress of the United States in 1891 appropriated ten thousand dollars to cover the expense of an experiment in rain making. Across the Potomac River, near Washington, on a muggy night, nearly half a ton of a noisy explosive, known as rackarock, a nitroglycerin compound, was detonated. It was a night when the clouds hung low and the atmosphere was nearly saturated, a condition considered favorable for the production of rain by those who believed in the so-called concussion theory. There were light showers from time to time, but these occurred just as frequently before the explosions as during or immediately following. And so the consensus of opinion among those who followed the experiments closely was that the explosions had no direct effect in producing rain. A few weeks later the rain makers moved to Texas to conduct their experiments. The claim was made that on a certain date rain followed as a result of the explosions; but, unfortunately for those who made the claim, it was soon established beyond doubt that natural rain had fallen not only at the place in question but over a wide extent, and that the rain area had progressed across the country.

Early experiments with explosives

In brief, the noise making proved nothing, and the attempt to cause precipitation by concussion was held up to ridicule (properly so) by scientific men. The basis of this belief that gunfire or explosions would produce rain was a statement in a certain book, on *War and Weather*, that great battles were always followed by heavy rains. This is *not* the case, and unbiased examination of weather records shows beyond doubt that there is no such relation. Heavy gunfire is by no means always followed by rain.

Gunfire not a cause of rain

An amusing incident of the discussion following the trials at Washington and Texas was a much debated reference to Plutarch's allusion that "extraordinary rains followed great battles." The reference is to the defeat of the Ambrones, by Marius, 102 B.C. Now certainly there was no gun firing at that date, and it requires some stretch of imagination to picture

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the shouting of armies and the clashing of shields as effective agencies in producing rain. What seems to clinch the matter is that the heavy rains referred to fell many months after the battle.

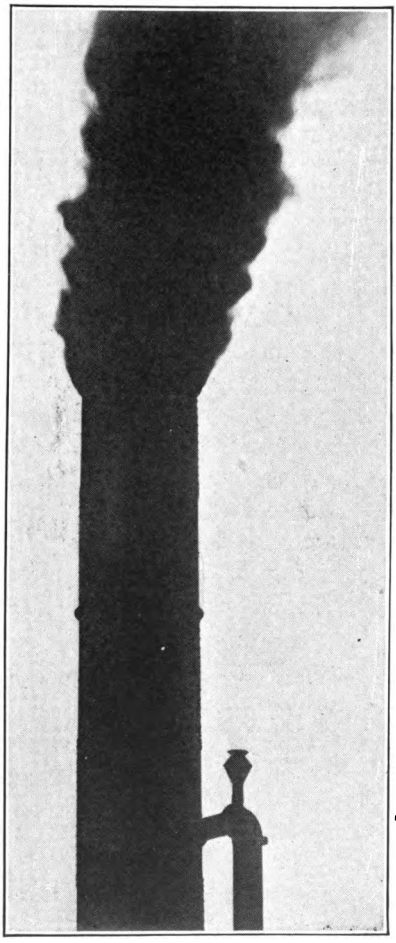

FIG. 34. POLLUTING THE AIR WE BREATHE

During the World War there were numerous instances of heavy artillery firing without subsequent rainfall. On the other hand, many of the heaviest rainfalls occurred during quiet intervals.

Probably the most interesting outcome of the study of weather in connection with war was not anticipation of rain, but successful forecasting of periods of anticyclonic winds and fair weather for offensive operations. Such weather was anticipated and prevailed at the time of the flight of the super-Zeppelins in October, 1916, and again for the German great offensive in March, 1918.

Gas and dust not causes of rain

Not much can be said in favor of the belief that releasing a vast amount of gas, or ejecting a great quantity of minute dust particles, will produce rain. If such a relation were a direct and causal one, cities where factories are numerous, and where chimneys are constantly belching forth huge columns of smoke, would have higher humidity and heavier rainfall than surrounding districts. Such is not the case. Something more than the presence of nuclei is necessary, *and that something is a sufficient degree of cooling.*

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From the work of the Committee for the Investigation of Atmospheric Pollution, we know that London domestic fires are largely responsible for the vast quantity of smoke which hangs over the city. In some of these famous smoke-produced fogs the weight of the suspended matter is nearly 200 tons. Yet even such great quantities fail to cause daily showers.

Smoke not a cause of rain

A positive illustration of the inefficiency of a large volume of smoke to produce rain unless temperature changes accompany the introduction of the smoke is given by Figure 35, which shows a stream of smoke from an extensive forest fire on Mt. Tamalpais. This moved inland over San Francisco

FIG. 35. STREAM OF SMOKE FROM FOREST FIRE

Bay, *above a stream of fog.* The height of the fog above sea level was about 100 meters, the height of the smoke about 500 meters. Aside from the internal heat of the smoke stream the air itself was warmer at the higher level. Usually there is a fall in temperature.

Artificial rain makers have more than once been put into embarrassing situations by the untimely arrival of rain. Ten years ago, during a prolonged drought in the southern counties of California, an ambitious rain maker offered to end the drought and produce rain by setting off a large quantity of explosives. A meeting of the authorities was called at a certain city and a general invitation extended to all interested to attend the meeting. While the meeting was in progress heavy rain began to fall and continued for some time. As there was, therefore, no need for the services of a rain maker, the meeting speedily adjourned.

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Now this incident is of more than passing interest, because if the meeting had been called a day earlier, and the explosives had been used preceding the rain, it would have been claimed that the rain was the result of the concussion; and this would

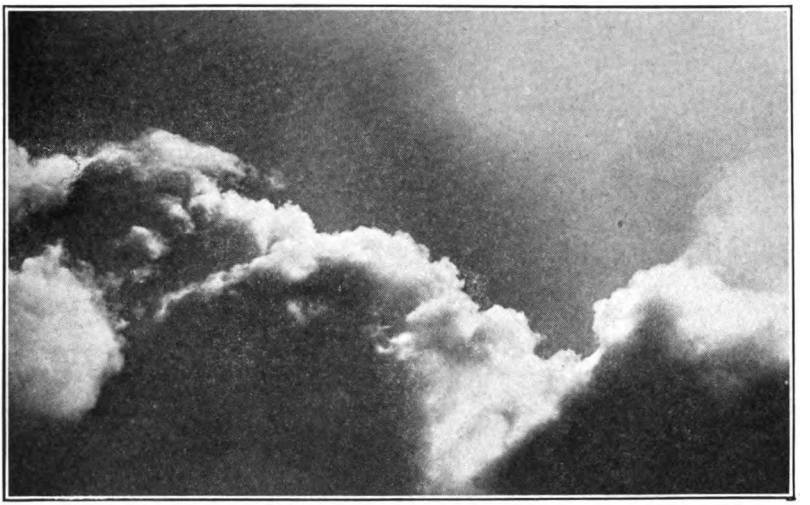

FIG. 36. EDGE OF A CUMULUS CLOUD. COOLING BY ELEVATION

have been widely promulgated and many would have been convinced that the proof was conclusive that rain could be produced by such methods.

10. Natural processes. We have all noticed the gush of rain that frequently follows a flash of lightning and a heavy peal of thunder. It would almost seem as if Nature were conducting before our eyes an elaborate experiment in rain making; indeed, as if the rain were actually shaken out of the clouds by the violence of the lightning discharge.

Now it is possible by electrifying drops to cause them to attract or repel each other, depending upon the character of the charge. A drop that is negatively charged is attracted by a drop having a positive charge. Also it is possible to develop an electrical charge and an electrical field that rapidly increases in intensity, by breaking up or atomizing raindrops. It is this process, we have good reason to believe, which produces the charge on a

Effect of electrifying raindrops

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thunderhead or cumulo-nimbus cloud. There is always an uprushing current of air carrying with it a load of raindrops. The stream of air twists and curls and rolls over on itself. The raindrops are broken into smaller drops, increasing the electrical charge; and when a certain intensity is reached there is a break or rupture of the air mass between the charged clouds or between a cloud and the earth, and this we call a flash of lightning.

The electrical charge on the base of a large cloud may be sufficient to cause a flash which would equal the power of one hundred thousand horses exerted for a second. Generally the time is much shorter than a second, more often a thousandth of a second. The horse power would then be one hundred million.

Sound travels 332 meters[1] in a second, and light 298,860,000 meters in a second; hence we *see* a flash of lightning before we *hear* the thunder which it causes.

Many have thought that either the lightning or the thunder caused the rain gush; but, as the drops travel with a speed of only 10 meters per second, it is evident that even when 10 seconds elapse between seeing the lightning and hearing the thunder, the drops could have traveled only 100 meters while the cloud from which they are supposed to have been shaken is 3400 meters away. So it is plain that the drops do not come from the cloud. In fact, it would take them more than five minutes to travel the distance.

Neither the lightning nor the thunder seemingly is the direct cause of the rain gush. Dr. Simpson's new theory is that electrification is brought about by vaporization of

[1]The following are the most recent values for sound in the free air as determined by the author, 1923. See *Harvard College Observatory Annals*, Vol. 86, Part II.

Kilograde	Centigrade	Fahrenheit	Meters per Second	Feet per Second
1000	0	32	333	1093
20	5.5	42	338	1107
40	10.9	52	342	1122
60	16.4	61	348	1142
80	21.8	71	353	1162
1100	27.3	81	358	1174

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the drops within a cumulo-nimbus cloud. There are violent uprushes and downrushes. Possibly drops are carried earthward. A downrush might precede thunder; but, owing to the greater speed of the sound wave, we should nevertheless hear the thunder long before the drops reached the ground.

Effect of lightning and thunder on fall of rain

An experiment performed by an American physicist, Professor Millikan, should be referred to at this point. Between two plates with a potential difference of 10,000 volts (the voltage preceding a lightning flash may amount to 10,000,000, a thousand times greater) a very small drop of oil, from a jet blown across the top plate, is allowed to pass through a minute opening. The drop is electrified and the experimenter can make it move up or down between the plates by throwing on the field as

Millikan's experiment to detect electrons

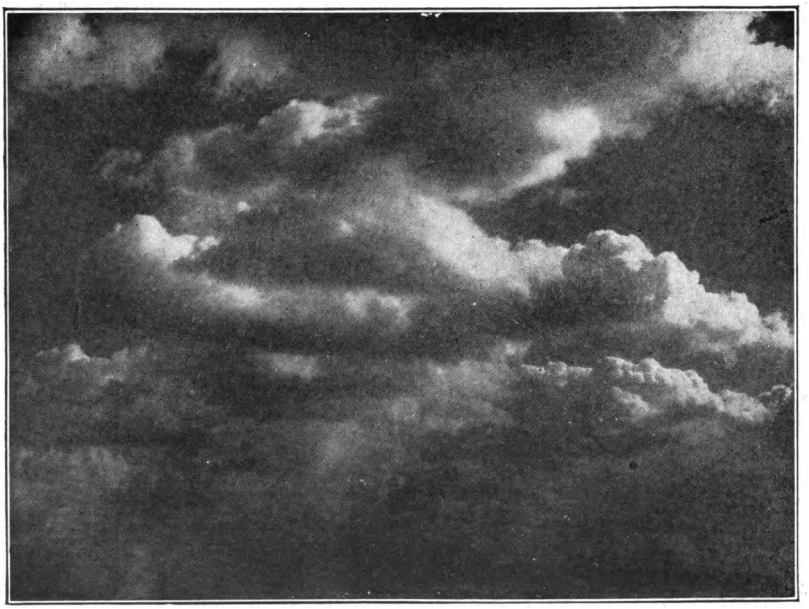

FIG. 37. THE MOST FREQUENT TYPE OF LOW CLOUD. EARLY AFTERNOON CUMULUS

the drop comes near the bottom, and throwing it off as the drop rises. The drop will capture ions and change its speed accordingly.

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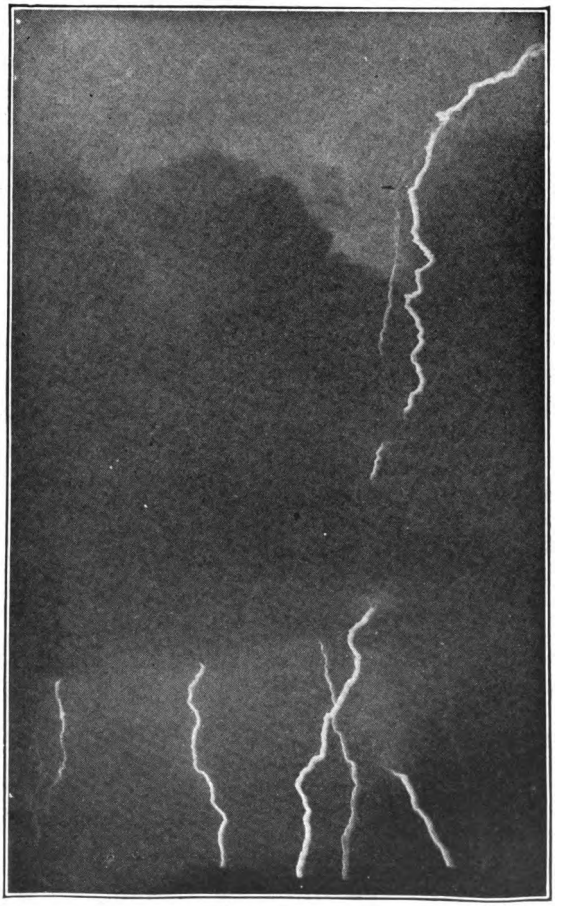
While the experiment is more directly concerned with the detection of electrons, it also throws light upon the motion of electrified minute bodies in a field of varying intensity. It is conceivable, indeed quite probable, that raindrops not far above the ground have their speed greatly accelerated when a flash of lightning occurs. They are doubtless highly charged, and so move rapidly to earth at such times.

Speed of raindrops accelerated by lightning

11. The electrification of raindrops. Many years ago Rayleigh, Lodge, Bidwell, and others showed how responsive a jet of water is to an electrically charged surface brought near it. It was also shown that a dusty atmosphere could be clarified quickly by one or two large sparks from an electrical machine.

In 1886 McAdie, experimenting with a jet of water at the top of the Washington Monument, noticed that an electrified jet of water from an insulated source broke into fine spray during thunderstorms. The stream was



McAdie

FIG. 38. LIGHTNING DISCHARGE THROUGH CLOUDS

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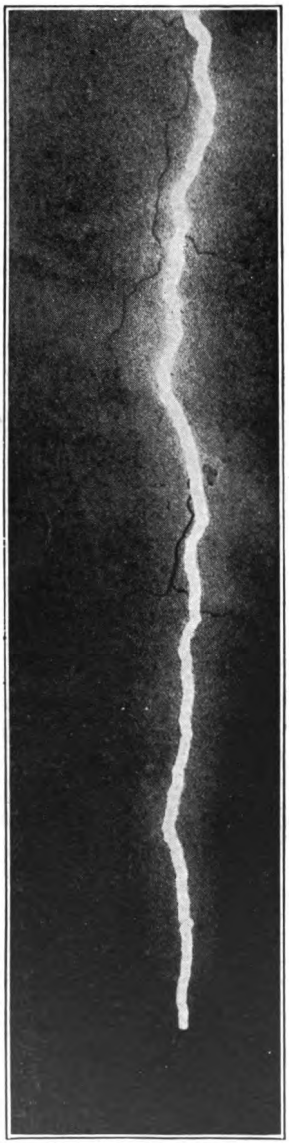

FIG. 39. A LIGHTNING FLASH
Estimated potential 1,000,000 volts; current 100,000 amperes; duration 1/1000 second; power 100,000,000 kilowatts

twisted and distorted as each charged cloud drew near; but when a flash of lightning occurred it immediately resumed a normal condition. In other words, the water drops were exceedingly sensitive to the increasing electrification.

Origin of electric charge

The one theory accounting for the origin of the electric charge in thunderstorms which seems to fit best the observed phenomena is that advanced by Dr. G. C. Simpson, which traces the electric separation which develops into lightning back to the breaking up or pulverizing of raindrops. As has been mentioned above, in a thunderstorm there can be and nearly always is an intensive shattering of the raindrops. There is also a filtering of the drops, and probably the water is much purer than ordinary water. This is of some importance because it has been recently shown by Nolan and Enright that the purer the water the greater the electric charge. They have shown, too, that a drop of rain of average size, say 4 millimeters in diameter, if broken up into 27 equal drops, causes a surface change of 30 square centimeters. This can produce a quantity of electricity of more than 0.2 electrostatic unit per cubic centimeter. In a cloud, therefore, the quantity of electricity thus developed is amply sufficient to account for lightning flashes. And just as long as the operation of breaking up raindrops of, let us say, 5

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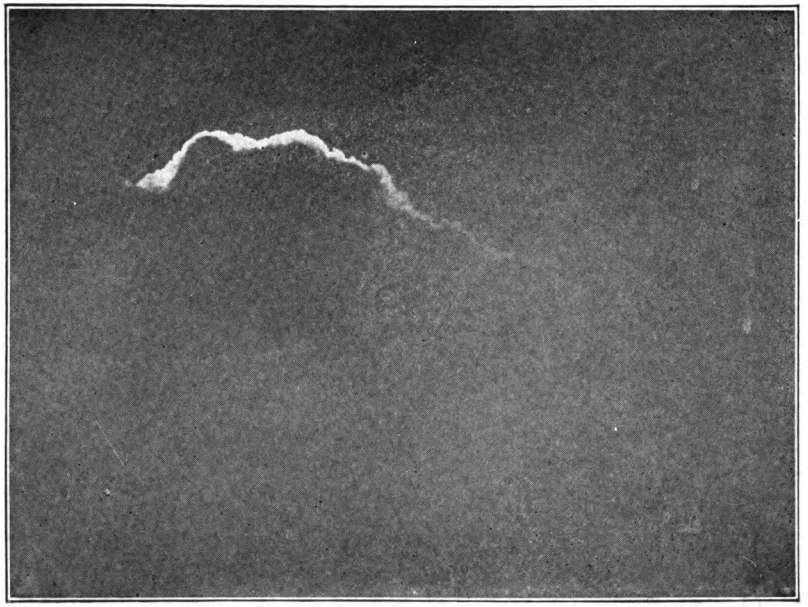

FIG. 40. EDGE OF A CUMULUS CLOUD. THE SILVER LINING

millimeters diameter into drops of 0.005 millimeter diameter continues, just so long will there be lightning. A thunderstorm ends when the breaking up of raindrops by uprushing currents ceases.

12. Cloud particles and raindrops. What may be called droplets are very small, varying from 0.005 to 0.02 millimeter in diameter. Compared with molecules, however, they are very large, for in one cubic centimeter of gas there are 2,700,000,000,000,000,000 molecules. In the same space there are twice as many atoms and three or four thousand times as many electrons.

Dust particles vary in size from large aggregations known as motes, which are seen in a sunbeam, to extremely small particles, less than 0.00001 millimeter in diameter.

Dust or smoke particles nuclei of condensation

Smoke particles, like dust, are of various sizes. In one of his many papers on "Counting Dust Particles in Air," John Aitken states that a cigarette smoker sends into the air, with each exhalation, 4,000,000,000 particles. In general, these minute

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dust or smoke particles serve as nuclei or centers of condensation.

By the use of methods devised by Professor Barus, the number of nuclei has been measured at various times over

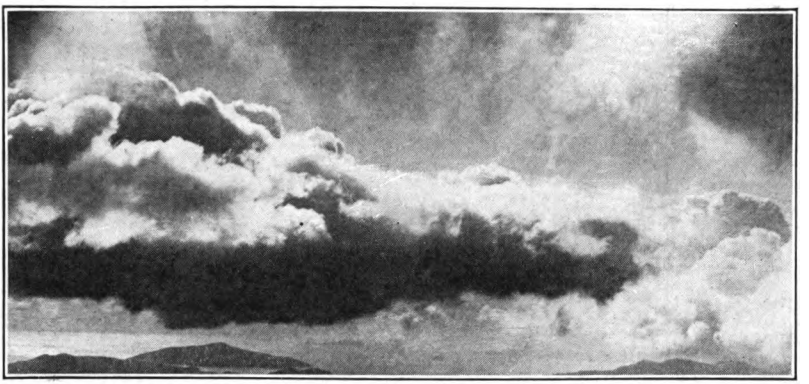

FIG. 41. WATER VAPOR RISING AND CONDENSING INTO CUMULUS

land and sea. These nuclei, however, must not be confused with what the physicist calls nuclei—that is, atomic centers—for the nucleus of an atom is infinitesimally small, being only 0.000,000,001 millimeter.

Size and velocity of raindrops

Raindrops are of immense size compared with atomic or molecular dimensions. The smallest drops which reach earth are about 0.01 millimeter and the largest drops about 5.5 millimeters in diameter. The terminal velocity of very small drops is low, about .03 millimeter per second, while the largest drops fall, as we have already noted, with a velocity of 8 meters per second, or 18 miles an hour. When a current of air rushes upward at a speed equaling or exceeding this, then no rain will fall.

The volume of raindrops varies from small drops, as small as 0.002 cubic millimeter, to large drops, 80 cubic millimeters.

In an ordinary drop, the radius of the drop being 0.25 millimeter, the surface is 0.78 millimeter squared, and the volume 0.065 cubic millimeter. In a minute about 10 such drops will fall on a space of one square centimeter.

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13. Atmospheric dust. At the last meeting of the British Association for the Advancement of Science, the meeting at Hull, 1922, an interesting paper describing a new instrument for measuring the dust content of the air was described by Dr. J. S. Owens. The instrument is really a cloud maker and cloud dissipator, leaving behind a residue of minute dust particles.

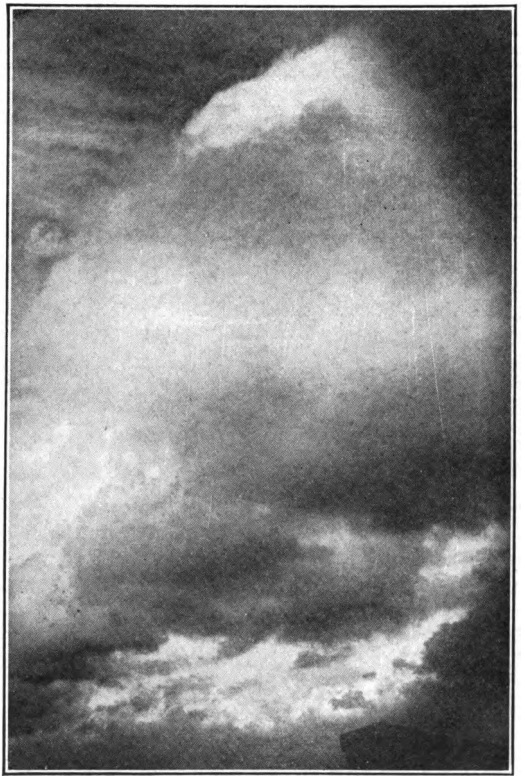

FIG. 42. A REAL RAIN MAKER

The principles made use of are reduction of pressure, and expansion with consequent condensation of whatever moisture may be present. A ribbon-shaped jet of air is made to impinge at high velocity upon a microscope coverglass. The dust particles adhere to the glass and the water is evaporated. There results a linear deposit of dust 10 millimeters in length. Fifty cubic centimeters of air are used for each count.

Owens' measurement of dust content of air

Dr. Owens gave the results of many measurements. He discovered that aside from other matter there were many spherical transparent particles with diameter of 1.5 microns (the micron is one-millionth of a meter). These particles are not soluble in water, xylol, or oil and do not stain. They are not pollen grains or micrococci and probably are of volcanic origin.

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Records of dust found in the atmosphere at different places were mentioned as follows:

Sept., 1922		Particles per cc.
2	Holme, Norfolk, Sea Coast	152
5	Brighton	1380
10	Hull	3080
(Sunday)	Hull	3080
11	Hull	13800
(Monday)	Hull	13800
(Monday)	Hull (seaward of Spurn Head)	140

A fundamental difference between the dust-counter described and Aitken's is that, in the former, dust particles are examined under a high power and water drops are not taken into account, as all water has evaporated from the record before examination. In Aitken's dust-counter the only particles counted are water drops, in each of which a dust nucleus is assumed to be present, although invisible, since a low-power objective must be used.

Cause of London fog

For some years a Committee for the Investigation of Atmospheric Pollution has published annually reports of measurements of deposits as collected at some thirty or more stations in Great Britain. It appears clearly that domestic fires are responsible for nearly two-thirds of the total smoke in the air over London. Dr. Owens, writing on "London Fog in November," describes with some detail the measurements of the black particles. These varied from 0.00013 millimeter to 0.00026 millimeter in diameter. The thickness of the water film was probably 0.0014 millimeter. He compares these with the diameters of fog particles measured by Barus in his experiments on atmospheric nucleation.

Regarding the source of the particles in London fogs, Owens finds that they come quickly, the air being relatively clean at 6:00 A.M. and heavily laden with smoke fog at 9:00 A.M.

When the air in London is fairly clear, in winter, the quantity of suspended matter is approximately 1 milligram per cubic meter, while during a dense fog it rises to 5 mgs/m³. A rough estimate of the weight of the impurity in a fog for

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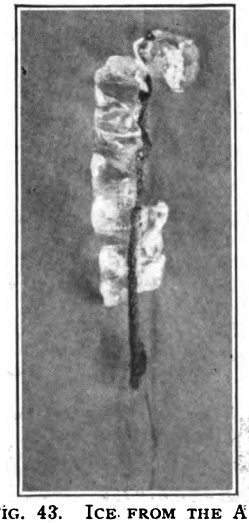
an area of 310 square kilometers (120 square miles) and up to a height of 122 meters gives 193 tons.

Fry at Cincinnati, working for the Smoke Abatement League, found about 720 grams to the square meter. This would be over two thousand tons to the square mile. Measurements of the monthly deposit of soot in Pittsburgh showed that at the place of maximum deposit the annual rate was 4000 grams to the square meter and at the place of minimum deposit 1000 grams.

Soot deposit in Cincinnati and Pittsburgh



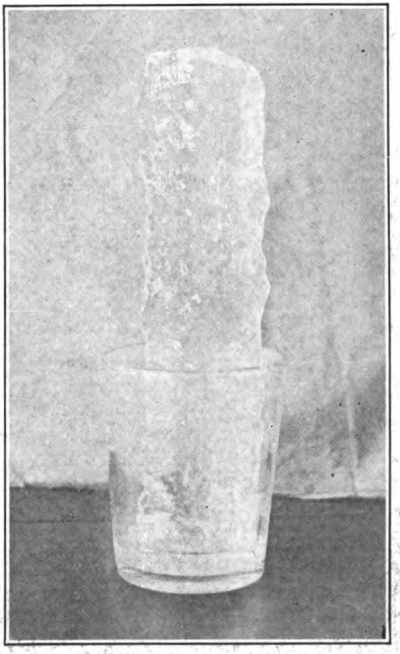


FIG. 43. ICE FROM THE AIR. COATING ON WIRE DURING AN ICE STORM

Besides the carbonaceous and ashy dust which comes from combustion, there may be dust from what may be called natural sources. Thus Winchell and Miller studied the remarkable dust fall of March 9, 1918, in Iowa, Wisconsin, upper and lower Michigan, and as far east as Vermont, covering an area of one hundred thousand square miles. They calculated that

Dust from natural sources

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not less than a million tons of organic and inorganic material fell, and probably many times that quantity. The particles consisted chiefly of feldspar, quartz, opal, limonite, and other inorganic matter, but there were also bits of plant tissue.

Search for the origin of the dust was facilitated by the fact that a snow cover lay over the country to the north and that rain had fallen in many localities during preceding days. A map shows the areas thus eliminated as probable sources.

Cyclonic disturbance responsible for dust deposit

A well-defined cyclonic disturbance was moving across the continent, having entered Northern California March 7. This led to an investigation of meteorological conditions in the arid regions of the Southwest, particularly in New Mexico and Arizona, where are located large areas of siliceous feldspathic rock. It was learned that strong convectional currents had prevailed

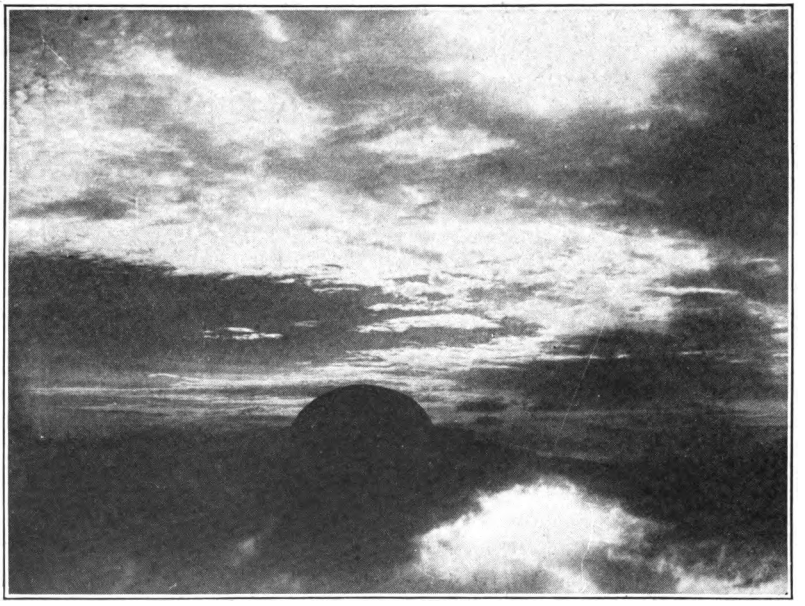

FIG. 44. CLOUD AND REFLECTION IN A POOL OF WATER

there on March 5, raising dust storms so severe as to cause much discomfort at the military camps. From a study of air currents as given by the Weather Bureau, the investigators

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concluded that an enormous quantity of dust must have been eroded from these arid regions, lifted into the upper atmosphere, and carried with the storm a thousand miles or

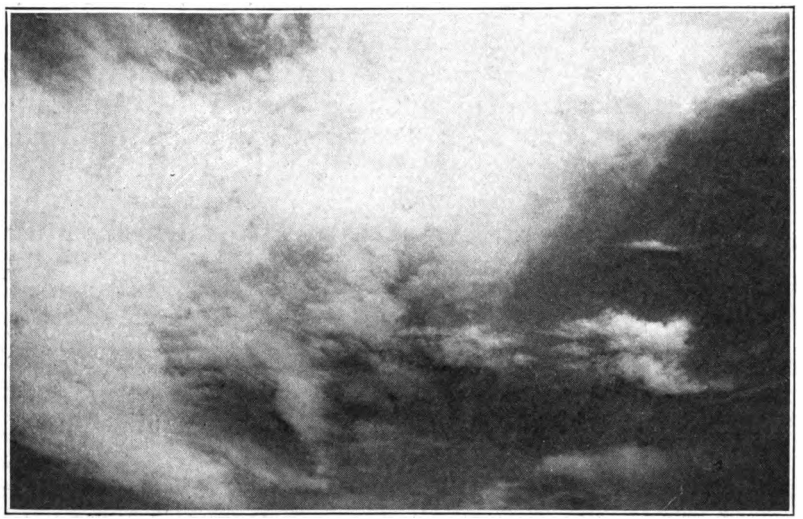

FIG. 45. TURBULENT ALTO-STRATUS

more to the northeast, where it was brought down by the snow and sleet which had formed at a great altitude in the air.

14. Heavy rainfall. Rainfall is not measured by weight. Depth and rate of fall are considered preferable. In the heaviest rainfall thus far measured, there fell in one minute approximately 20 millimeters. An equivalent weight per square centimeter would be 12.5 grams; which means twenty times as many drops as in an ordinary rain. Such downpours, however, seldom last more than one or two minutes. In the heaviest known 24-hour rainfall the rate per minute averages 0.8 millimeter. This rain fell at Baguio, Philippine Islands, on July 14, 1911, and amounted to 1168 millimeters (45.99 inches). As much rain fell in one day as would fall in a year at New York City. The greatest hourly quantities were 91 millimeters and 90 millimeters; the greatest 10-minute rainfall, 18 millimeters; and the greatest 5-minute rainfall, 10 millimeters.

Heaviest rainfall recorded

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The heaviest 24-hour rainfall that has been recorded in the United States occurred at Taylor, Texas, September 9–10, 1921, after a prolonged drought. The quantity was 587 millimeters (23.11 inches), as much rain as London gets in a year.

It is doubtful if any one region can be at present regarded as the *rainiest place in the world*, for it is not easy to get reliable records in certain mountain regions where it is known that rainfall is very heavy. There are several places which, however, lay claim to the distinction of being the *wettest spot on earth*. Cherrapunji comes first. Dr. Simpson says that the annual rainfall at Cherrapunji, on the south side of the Khasi Hills in East Bengal, is the heaviest in the world, averaging 10,770 millimeters (over 35 feet). There was one year when twice this quantity fell. It is a far cry from India to that Armenian giant, Noah's mountain, Ararat.

The rainiest place on earth

There are probably some localities in the mountains on the Hawaiian Islands where the rainfall is as heavy as in the mountains of India. Larrison, of the United States Geological Survey, claims that at Mount Waialcale, island of Kauai, the annual rainfall approximates 40 feet.

15. Light rainfall. So much for heavy rainfall. Let us now look at the other extreme and inquire, What is the dryest place on earth? Naturally desert regions suggest scant rainfalls. In true desert areas the rainfall will not exceed 250 millimeters (10 inches) in a year. There are, however, deserts with ample rains where lack of vegetation is due to various causes other than want of rain.

Perhaps the most interesting case of deficient rainfall in the United States is the region just east of the Sierra Nevada. This has been called the Land of Little Rain. But one can never be too sure about such matters. Professor Langley, who camped near the top of Mount Whitney, saw hardly a cloud during a stay of a month. The writer was a member of an astronomical party, under Dr. Campbell of the Lick Observatory, which spent a week on the summit of Mount Whitney, elevation 14,502 feet, the highest in the United States excluding Alaska. It rained five out of seven days.

Regions of deficient rainfall

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At Death Valley, California, not far to the southeast of Mount Whitney, there have been periods of six months in which no rain fell, or so small a quantity that no definite measurement could be made.

16. Droughts. What is an *absolute* drought? According to the ruling of the British Rainfall Organization, it is a period of more than 14 consecutive days without 0.25 millimeter (0.01 inch) of rain. A *partial* drought is a period of not less than two weeks during which the total rain does not exceed 6.2 millimeters (¼ inch).

Absolute and partial droughts defined

The definitions are necessarily incomplete, for they take no account of the expectation or probability of rain. For regions in which the normal rainfall is 1000 millimeters well distributed throughout the year, the above definitions hold. The expectation of rain is 5 to 10 per cent of the time, that is, 436 to 872 hours. In arid regions these figures fall to 1 per cent, 88 hours or less. It is said that at Lima, Peru, a shower may be expected once in fifty years.

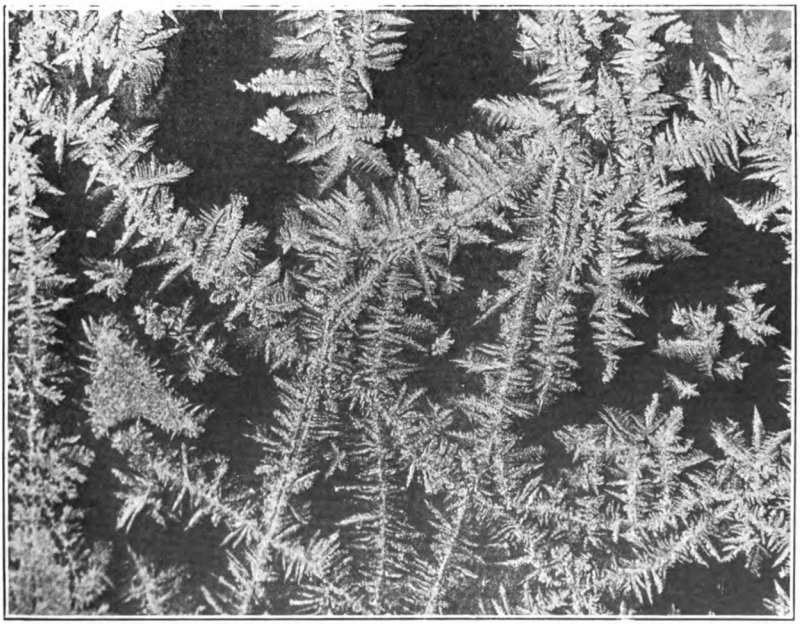

FIG. 46. FROST FORMED DURING A DIFFERENCE OF 100 KELVINGRADS (50 FAHRENHEIT DEGREES) BETWEEN INDOORS AND OUT OF DOORS

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17. Robbing the clouds. Some great rivers of air flow around the world from west to east, known as the Prevailing Westerlies. To offset these, there are other equally great counter currents flowing steadily from the east. Chief of the last named are the steady currents known as the Northeast and Southeast Trades, the word meaning "steady," an old English definition, and not business as one might infer.

The monsoon

Alexander of Macedon, returning from India, brought back the story of the monsoon—that mighty breath from the Indian Ocean. For the prosperity of India, then as now, was dependent upon the arrival of this wind with its copious offering of rain. The word *monsoon* means "season." If the rains are plentiful, then the harvest is large; but if the monsoon is late in coming, and withdraws quickly, then crops fail and famine threatens.

The monsoon is the rain maker for India. But why does it vary and how does it function?

To begin with, it is apparently not a Trade wind, for it is the west wind of the Arabian Sea blowing toward the west coast of India, and on over the land and the Bay of Bengal, where it is then twisted into a southerly wind.

Dr. Simpson, formerly of the Indian Meteorological Service, but now director of the British Meteorological Service, has traced back the wind and finds that the circuit is like a gigantic **S**.

Circuit of the monsoon

Beginning at the bottom of the **S**, the air rushes eastward past the Cape of Good Hope to Western Australia, a great west wind. But the slant is northward, and getting into tropical latitudes there is recurving and mingling with the southeast Trade. Now we are at the middle of the gigantic **S**. Crossing the equator and working north, it recurves for the second time over the Arabian Sea and blows into the box made by the Himalayas, the Khasi Hills, and the Western Ghats. The air has traveled a far distance over warm water and is saturated. There are 25 grams of water in every cubic meter of space. If half of this can be condensed and the process continue for many days, heavy rainfall, of course, results. At the end of a long journey the air stream, moving now from south to north, impinges on the mountains. To get past, it must rise 1000 meters;

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and the cooling due to expansion is sufficient to produce a drop of rain from every gallon of water vapor that is uplifted. The mountain ranges, then, are the great rain robbers. But if the stream flows into a warmer region, there is no stealing of rain. Or again, if the monsoon, for reasons which are becoming known but which lie beyond the scope of this paper, is of feeble strength, and has not made a long journey, then the rainfall is light. A slight deflection to the east or south and the mountains are powerless to make rain.

How mountain ranges act on the monsoon

Winds, then, are the master molders of clouds. He who would make rain must know something about the load of vapor and the way the up and down currents (for there are such currents, though we lack wind vanes to tell us of their direction and anemometers to measure their velocity) operate on the vapor.

Winds the molders of clouds

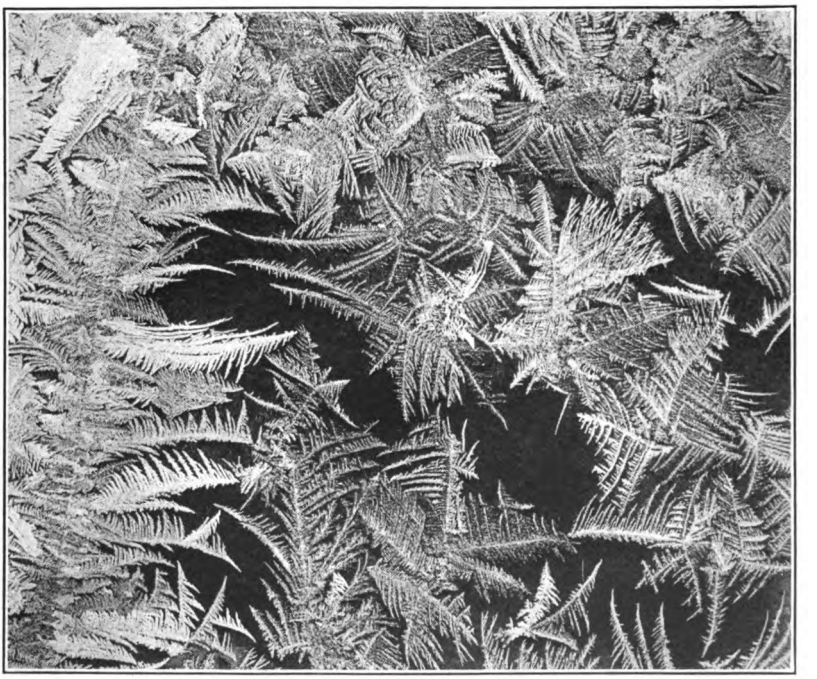

FIG. 47. ICE FROM THE AIR. FROST FEATHERS

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Most clouds are due to uplift cooling; but there are some clouds, as the dry weather anticyclonic haze, in which the downflow brings warm dusty air earthward. Finally, there must be a high absolute humidity. The rain maker who attempts to make rain when the absolute humidity is low undertakes to make something out of nothing—a difficult proceeding.

HUMIDITY AND RAINFALL

18. Moisture content of air. The following table, never before published, shows the annual absolute humidities, the relative humidities, and the rainfalls at 50 selected stations in the United States. Unfortunately we have no instrumental records of the moisture content of the air at Death Valley. We may surmise that the annual absolute humidity would be below 3 grams per cubic meter of space and the relative humidity below 40 per cent.

Humidity and rainfall in the United States

Perhaps the most remarkable case of an especially dry day in the country east of the Mississippi occurred at Blue Hill on April 8, 1917, when in the afternoon for a few hours there was an absolute humidity of only 0.08 gm/m³ and the relative humidity was only 1.4 per cent. The average daily absolute humidity is 6.0 grams and the relative humidity 74 per cent.

TABLE OF ANNUAL HUMIDITIES AND RAINFALL

		Absolute humidity in grams per cubic meter	Relative humidity or percentage of saturation	Rainfall in millimeters
			Per Cent	
1.	Tonopah.....	3.8	45	250†
2.	Yellowstone Park ..	4.1	66	500
3.	Winnemucca.....	4.5	52	215
4.	Santa Fe.....	4.5	49	200
5.	Cheyenne.....	4.6	56	130
6.	Flagstaff.....	4.6	61	510
7.	Denver.....	4.8	52	350
8.	Salt Lake City.....	5.0	52	400
9.	Bismarck.....	5.7	70	475
10.	St. Paul.....	6.5	72	725
11.	Portland, Me.....	6.7	74	1087
12.	Asheville.....	6.9	78	1082

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TABLE OF ANNUAL HUMIDITIES AND RAINFALL—*Concluded*

		Absolute humidity in grams per cubit meter	Relative humidity or percentage of saturation	Rainfall in millimeters
			Per Cent	
13.	Binghampton	7.1*	80*	847†
14.	Milwaukee	7.3	75	787
15.	Buffalo	7.4	75	950
16.	Dodge City	7.6	67	515
17.	Grand Haven	7.6	78	884
18.	Seattle	7.6	77	940
19.	Portland, Oregon	7.6	74	1158
20.	Detroit	7.6	76	818
21.	Boston	7.7	72	1110
22.	Toledo	7.9	74	782
23.	Cleveland	8.0	74	904
24.	Chicago	8.1	74	848
25.	Sacramento	8.3	67	505
26.	New York	8.4	72	1138
27.	Yuma	8.4	43	68
28.	Indianapolis	8.4	70	1064
29.	Pittsburgh	8.4	72	935
30.	Columbus	8.4	72	942
31.	San Francisco	8.5	80	572
32.	Cincinnati	8.6	69	975
33.	Philadelphia	8.6	70	1031
34.	Baltimore	9.0	69	1102
35.	Washington	9.2	70	1095
36.	Atlantic City	9.3	80	1065
37.	Los Angeles	9.3	70	395
38.	St. Louis	9.3	70	942
39.	Richmond, Va.	9.6*	78*	1108
40.	San Diego	10.1	74	239
41.	Atlanta	10.3	72	1267
42.	Norfolk	10.8	78	1270
43.	Charleston	13.0	78	1356
44.	Savannah	13.0	78	1295
45.	Pensacola	13.8	78	1443
46.	New Orleans	14.1	78	1463
47.	Jacksonville	14.3	80	1356
48.	Galveston	15.0	81	1209
49.	Corpus Christi	15.6	82	681
50.	Key West	17.5	78	963

*Partial.
†To convert to inches multiply by 0.04.

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The table does not prove everything concerning rainfall. Indeed, one of the most common mistakes in scientific work is to attempt to prove cause and the effect from data which

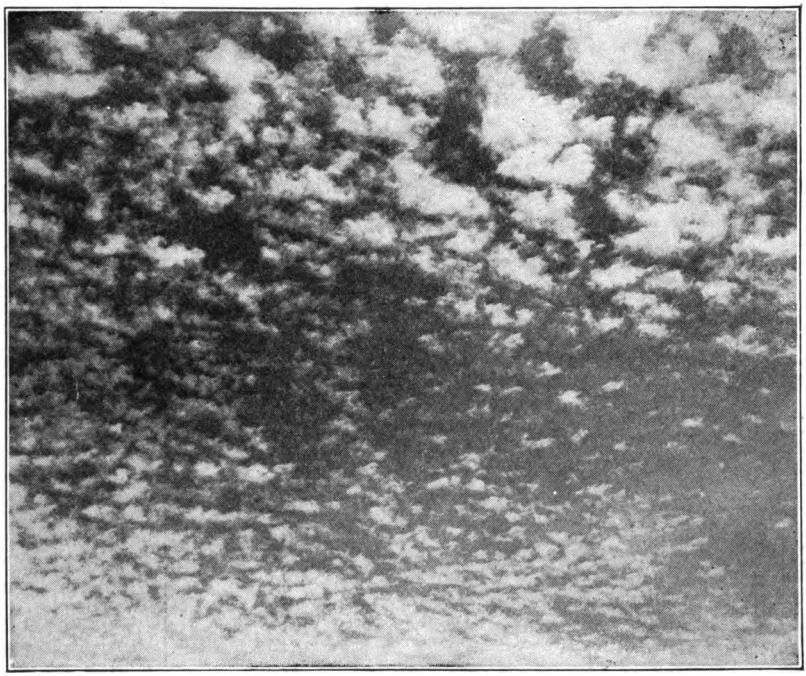

FIG. 48. NURSLINGS OF THE SKY. ALTO-CUMULI

have a certain correlation. Likewise many faulty deductions have been drawn from mean values. Furthermore, with regard to the control of rain, remember that there are other factors than the mean quantity of water vapor. As we have tried to emphasize, there must be cooling of the vapor, brought about in some way, most commonly by motion, either vertically or horizontally. Some rains are purely convective effects, that is, the cooling is due to uplift; other rains are advective effects, that is, the water vapor is brought in horizontally or on a gradual incline, and the cooling is due to causes other than elevation expansion.

Deductions drawn from table

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The table does show that on a yearly quantity basis there is four times as much water vapor present along the Gulf Coast as in the arid region east of the Sierra Nevada. The rainfall is also about four times as heavy on the coast as in the arid section.

There is one exception, however—Yuma, where the rainfall is scant although the mean annual vapor weight is comparatively large. It is not generally known that Yuma in summer has a higher vapor pressure than New York.

Again, San Diego, while essentially a damp climate if we are to judge by the weight of the water vapor, has but a scant rainfall, only one-fifth of what might be expected. Absence of wind probably accounts for the diminished rainfall. Differences in elevation must also be taken into account. In the free air a rise of 1000 meters is generally accompanied by a fall in

The real rain maker

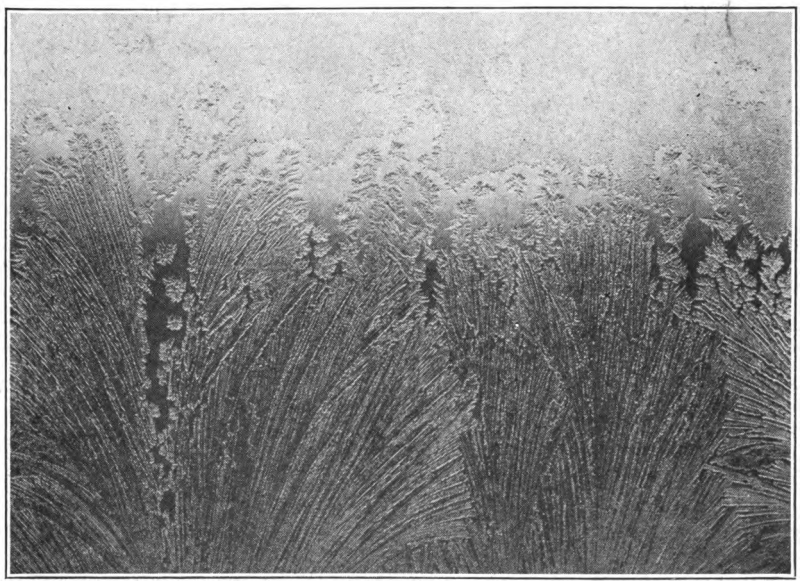

FIG. 49. FERNS OF FROST

temperature of 20 Kelvingrads. Furthermore, air flowing north 1000 kilometers (600 miles) is cooled just about as much as if it had risen 1000 meters. Hence the real rain

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maker is a stream of warm air with a heavy load of vapor, rising and cooling, and at the same time flowing north or into a cooler region.

19. Recent experiments. Professor W. D. Bancroft and Mr. L. Francis Warren have quite recently sprayed fog banks over flying fields with electrically charged sand from above.

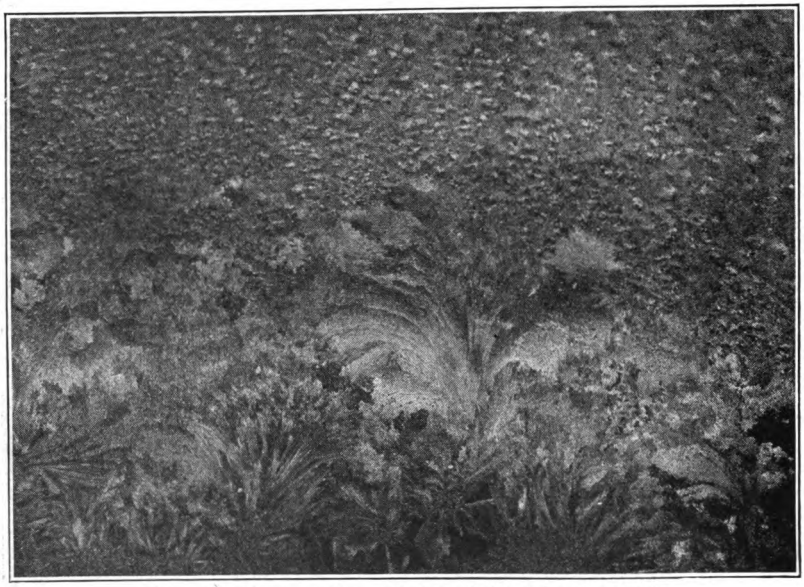

FIG. 50. ONE OF JACK FROST'S MANY AUTOGRAPHS

Experiments at McCook Field by the Army Air Service, using 80 pounds of sand, with a potential of 15,000 volts, dissipated a thick cloud in ten minutes. At present the object is to clarify the air and remove the fog rather than attempt the production of rain. While a moderate success may be obtained in dissipating fog, it is doubtful if the method will prove an efficient rain maker. It must be remembered that the lower air is frequently sand-laden and that these sand particles may be electrified by friction, yet no rain follows, nor is there any evidence of condensation on the particles.

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CONCLUSIONS

1. Rain makers who have thus far received publicity by press notices have not, as a matter of fact, succeeded in making rain. Their claims have never stood investigation by competent and impartial judges. Indeed, there has been considerable misrepresentation and not a little imposition on a gullible public.

2. No present methods promise a solution of the problem.

3. We may eventually be able to dissipate fog in aërodromes and over landing fields. It is a matter of great importance in connection with aviation that a clear space be provided for landing.

4. It is possible within limited space to clarify a dusty or foggy atmosphere by means of electrical discharges.

5. On a larger scale, as, for example, over cities and towns or over a harbor of moderate size, such clarification cannot at present be successfully achieved because the fog is reproduced as rapidly as it can be dissipated.

6. It would require all the output of electrical power of a dozen large hydroelectric plants to dissipate a sea fog over an area of five or ten acres, provided the wind was light.

7. Rain makers and fog dispellers alike underestimate the dimensions involved; and, furthermore, they fail to realize that it does not follow that, because an experiment may be successful in a laboratory, it must therefore be successful when repeated on a vastly greater scale.

8. Chiefly because of the large areas involved, it is not likely that any scheme based on present knowledge can be a financial success.

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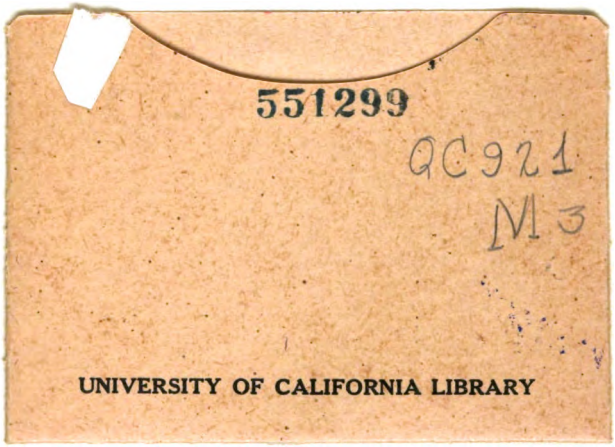
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